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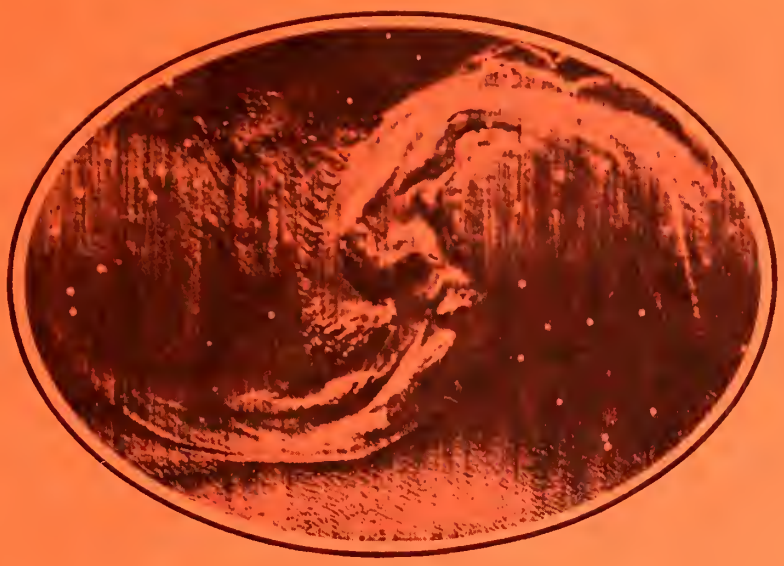

Man's Geophysical Environment | Its Study from Space

A REPORT TO THE ADMINISTRATOR OF ESSA

MARCH 1968

PENNSYLVANIA STATE UNIVERSITY
SEP 10 1968
DOCUMENTS COLLECTION

U.S. DEPARTMENT OF COMMERCE
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION

Man's Geophysical Environment | Its Study from Space

A REPORT TO THE ADMINISTRATOR OF ESSA

Prepared by a Special Task Force of the
Environmental Science Services Administration
under the chairmanship of
Dr. J.P. Kuettner

U.S. DEPARTMENT OF COMMERCE
C. R. Smith, *Secretary*

ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
Robert M. White, *Administrator*

MARCH 1968

Cover Photograph: An infrared line scan photograph showing an eddy, about 4 miles across. It was exposed at night in April 1963 approximately 200 miles east of Cape Cod. The instrument operates in the spectral range of 8-14 microns and translates small variations of infrared emission into a black and white image. The light tones represent greater infrared emission than the dark tones. The intensity of the tone contrasts can be varied with the electronic gain setting in the instrument.

Photograph courtesy of the U.S. Naval Air Development Center - Johnsville, Warminster, Pennsylvania.

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FOREWORD

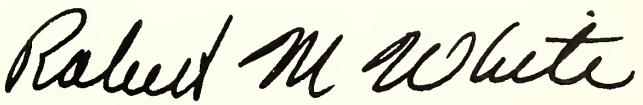
The continuing need to evaluate the potentialities of new technology for the study of man's geophysical environment led to my request to the staff of the Environmental Science Services Administration to conduct this agency-wide study of promising ways in which future manned and unmanned space platforms might be used in assisting ESSA to carry forward its mission responsibilities. A task team representing all disciplines within ESSA was formed under the direction of Dr. J. P. Kuettner, Chief Space Scientist, to carry out such an analysis and prepare a technical report which could be used as a basis for discussion within the executive branch of the government, and which could serve as a basis for eliciting further comment and suggestions from the nongovernmental, scientific community. A careful appraisal has been made by the task team of a wide variety of possibilities from which it has distilled a number of specific proposals in the light of present and anticipated developments in space technology.

Because both the requirements of ESSA and space technological capabilities are in a state of continuous flux, the proposals in this report reflect the best estimates of the task team at only one point in time; these estimates will be revised as new technological developments appear and as the needs of the organization change. The document must therefore be regarded as preliminary in nature.

There has been no attempt on the part of the task force to conduct a thorough economic benefits study; while the importance of such an analysis is fully recognized, the emphasis of this report has been on technical needs and potentialities.

The study concludes that we stand on the threshold of revolutionary new possibilities for the acquisition of geophysical information on a global scale. Such data are vital for providing a wide range of environmental services and are essential to the systematic scientific investigation of the planetary geophysical environment.

Recognizing that environmental data serve the interests of many agencies, both governmental and nongovernmental, and that individual sensors can produce data required to meet the mission needs of other federal agencies, it is my hope that this document will contribute to the emerging national discussion on future direction of the national space program.



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SUMMARY

Today, the environmental sciences are presented with a unique opportunity for major advances in most of their disciplines. Unprecedented progress in space technology, in remote sensing, in computer and data handling and in the mathematical modeling of atmosphere and oceans is being achieved at a time when the nation realizes the need for a multifold attack on its environmental problems.

In light of these developments a special task force representing all disciplines within ESSA has looked five years ahead in an attempt to appraise the potential utilization of manned and unmanned space platforms for the environmental sciences.

A review of present and future space vehicles* available to scientific users shows a wide range of payload capabilities from small special-purpose satellites to large manned or unmanned observatories. For the Saturn class vehicles, and using modified Apollo hardware, experimental payloads of the order of 10,000 lbs., 1 to 5 kilowatt power and several hundred cubic feet volume may become available for both low and earth-synchronous orbits.

Against this background the task force screened a large number of contributions from all quarters of the organization. To arrive at a selected group of proposals a number of criteria were taken into account. A major consideration was, of course, the question of whether a specific requirement supports ESSA's service and research missions. It should be understood that most proposals fulfill the requirements of various other agencies and institutes in the same disciplines and that they should not be interpreted to represent ESSA's sole responsibility. In fact, the multiple use and cross fertilization resulting from many of the proposed experiments is one of the aims of this report, which should be viewed from the standpoint of the total national effort involving earth-oriented space programs.

In addition to mission importance the following selection criteria were considered: technical feasibility and hardware availability; possible multipurpose utilization of instrumentation and data; superiority over conventional methods; and several other considerations listed in Table 2.1–B (p. 10).

A summary of proposals selected from the different environmental disciplines and a discussion of systems considerations follow:

SELECTED PROPOSALS

Space Disturbances must be monitored on a continuing basis to predict radio propagation conditions

*The term "space vehicles" as used here includes launch vehicles and spacecraft, manned and unmanned, but not ground-based sounding rockets or gun-launched probes, unless specifically noted.

and hazards to manned spaceflight. An operational space disturbance monitoring system is proposed for measuring solar protons, electrons, x-rays, ultraviolet radiation and solar radio noise from polar and synchronous orbits.

In the field of *Aeronomy and Telecommunications,* three proposals were selected.

a. Ionospheric currents and molecular constituents in the lower ionospheric regions should be measured in polar orbit.
b. World-wide ionospheric mapping by a versatile multi-purpose sounding system is proposed to predict optimum working frequencies for telecommunications and to enhance the understanding of ionospheric processes.
c. A global noise and interference survey is recommended to produce maps of radio noise sources and to determine the variability of interference levels at a given point and frequency.

In *Meteorology,* where weather satellites have already provided close to 700,000 television pictures, attention has been focused on new possibilities of major economic or scientific significance.

a. Global measurements of the vertical structure of atmospheric density, winds and water vapor are primarily goals of the coming "World Weather Watch" and are of vital significance to extended numerical weather prediction. Feasibility and limitations of global horizontal density sounding systems should be tested using electromagnetic frequencies unaffected by cloud cover. The same recommendation applies to global wind sounding systems based on advanced concepts such as the "crossed beam" technique.
b. Absolute ground and sea surface temperatures are needed on a global scale to incorporate the effect of heat sources and sinks in long range weather prediction. Advanced spectral radiometers are considered capable of providing true surface temperatures within 1 or 2°C in cloud free areas.
c. Global measurements of the surface roughness of the earth and oceans would aid in determining heat and momentum transfer in the atmospheric boundary layer, surface winds over the oceans and water vapor transport, in connection with the general circulation. Radar scatterometers are considered promising, but require further testing and development.
d. With regard to the artificial modification of the atmospheric environment, real-time information from synchronous satellites and two-way cooperation between field crews and highly trained space observers are considered for weather modification experiments. The weight lifting capability of the Saturn V class carrier rockets may be kept in mind if serious possibilities for large scale weather and climate modifications should develop in the foreseeable future.
e. Other proposals refer to the monitoring of electric activity in the atmosphere, to a global cloud census, and to a plan to combine the coming tropical field projects for the World Weather Watch with manned and unmanned space flight missions.

In *Hydrology*, the following surveys are recommended:

a. Areal snow surveys in major river basins, including the precise determination of snow lines in mountainous terrain.
b. River and lake ice distribution.
c. Interrogation of rain and river gaging stations by synchronous satellites and data transmission to selected hydrological centers. Such a low cost synoptic survey system may provide sufficient warning for potentially dangerous flood events.

In *Oceanography* and *Hydrography,* the following five subjects appear most promising:

a. World-wide surveys of unknown or doubtful shoals representing hazards to marine navigation. Color photography and infrared imagery will identify areas to which ships or aircraft can be dispatched for detailed charting.
b. Synoptic sea state characteristics over large ocean expanses using side-looking radar scatterometers.
c. Differentiation of water masses such as sea currents, estuary effluents, surface anomalies and water composition hazards, using color photography, as well as infrared and microwave radiometry and imagery to plot relative temperature differences.
d. Sea and lake ice surveillance from satellites has already been carried out on an experimental basis and deserves to be fully developed as an economic operational tool to protect marine navigation and to supply vital scientific data.

e. Data collection and relay of oceanic surface data from buoys by synchronous satellites.

In the field of *Geodesy,* a geometric-gravimetric experiment is recommended, to establish precise three-dimensional geodetic control in selected areas of the earth's land masses, and to determine the geometric shape of the geoid in its ocean-covered parts. The proposed instrumentation system comprises photographic frame cameras, panoramic and stellar cameras, laser and radar altimeters, with a total weight of about 1,500 lbs. (including film).

In the area of *Geomagnetism,* global surveys of the near-earth magnetic vector field are needed for both scientific and service oriented purposes, using three component precision magnetometers in low orbit.

To the field of *Seismology,* the transmission of seismological ground data by synchronous satellites is of importance, especially in connection with the "Seismic Sea Wave Warning System," "fault monitoring" system, etc.

SYSTEMS CONSIDERATIONS

Potential *instrumentation* systems and their multidisciplinary applications were compiled. The task force estimates that total weight, volume and power for a meaningful environmental instrument package will be of the order of several thousand pounds, several hundred cubic feet, and several kilowatts, respectively, well within the capability of the Saturn-Apollo class vehicles. Many of the required instruments are available or under development, others are recommended for vigorous development and testing, among them some highly promising and significant concepts for atmospheric density and wind sounding systems. Many sensors supplement each other and are capable of satisfying a variety of requirements.

With regard to the selection of *orbits* and their parameters, most environmental programs require polar (or at least high inclination) or earth synchronous orbits, For polar orbits optimum height for complete daily global coverage is over 1,000 km, which is not suitable, at this time, for continuous manned operations. Overlapping patterns for consecutive low inclination orbits were studied to evaluate the opportunity for a "second look" at interesting phenomena. Synchronous orbits are considered highly attractive for the environmental sciences.

With respect to the *data handling* problem, there is concern that environmental observatories with long mission duration will provide a data flux of such magnitude that serious problems may develop at the ground on the user's end, unless systematic planning is started at an early time.

The *role of man* in space was carefully analyzed and appraised from the standpoint of a scientific and operational user. Equipment oriented "service" and "operator" functions are distinguished from phenomena oriented "observer" functions and flight oriented "pilot" functions. Many of the proposed measurements appear to be suitable for either manned or unmanned spacecraft. Orbital repair and servicing of spacecraft systems by visiting crews is considered a promising concept, particularly where operational satellites are concerned.

The "observatory concept" was critically reviewed and favorably considered, but a number of operational requirements were stipulated. Multiple, simultaneous measurements of related parameters over the same location are highly valued both from a scientific and data handling standpoint.

CONCLUSIONS AND RECOMMENDATIONS

Some of the more important conclusions and recommendations* are:

- The study indicates that future space platforms will be capable of acquiring global geophysical data on an unprecedented scale for all disciplines of the environmental sciences and services.
- Convinced that manned and unmanned spacecraft supplement but do not exclude each other, the task force feels that an optimum combination of manned and unmanned space vehicles should be applied to future environmental science and service systems.
- An analysis of the data handling problem shows that an orbiting environmental observatory may provide data at such a rate that bottlenecks will develop on the ground unless efforts for improvement in software, data handling equipment and display devices are started in the immediate future.
- The task force urges development and testing of certain remote sensing concepts which hold great promise for environmental research and services; this is particularly true for radio occultation systems, remote wind sensing systems, radar scatterometer techniques and special spectral radiometers for the measurement of absolute surface temperatures.

*For further discussion of these and other conclusions and recommendations see Chapter 4.

- The task force rates highly a space vehicle capability:
  (a) to service and repair, in orbit, vital components of unmanned spacecraft (requiring accessible modular component design),
  (b) to provide a semi-automatic mode for manned spacecraft such that on board systems continue to operate after the flight crew leaves,
  (c) to launch from orbit after proper checkout, subsatellites, special probes and recovery capsules.
- Based on the commonality of sensors, spacecraft and data handling requirements the task force recommends that the interested user agencies take joint steps, at an early time, toward a coordinated national effort for the development and use of earth-oriented space technology.

INTRODUCTION

As pointed out in the Foreword, this report is the result of a request by the ESSA Administrator to explore the potential uses of future space platforms, both manned and unmanned, for the environmental sciences.

An agency-wide ESSA task force covered the following disciplines: Space Disturbances, Aeronomy and Telecommunications, Meteorology, Hydrology, Oceanography and Hydrography, Geodesy, Geomagnetism, and Seismology.

Looking about five years ahead, the ad-hoc panels of this task force appraised: (1) ESSA's geophysical requirements with regard to research and services, (2) the technical feasibility of satisfying these requirements with space monitoring systems, (3) related data handling problems, and (4) comparative aspects of future manned and unmanned space platforms.

The members of the task force and the numerous contributors to this effort throughout ESSA are listed at the end of the report. It is by their combined efforts that this study has been accomplished. NASA's contributions to Chapter 2, through which current and proposed space activities of that agency can be related to ESSA programs, are gratefully acknowledged.

chapter 1
THE CHALLENGE

1.1 A TURNING POINT

The environmental sciences are at a turning point. Not only has the nation realized the need for a multi-pronged attack on its environmental problems, but four major technical and scientific advances coincide with this development, giving the environmental sciences a singular opportunity.

First, the enormous national investment in space technology may soon make available manned and unmanned space platforms with unprecedented capability in power, size, and weight to serve as versatile geophysical observatories in space.

Second, the new technology of remote sensing is undergoing explosive development. Just when it has become abundantly clear that complete global data coverage is required to extend, for example, objective weather forecasting to one or two weeks, this new aspect of technology demonstrates how man can free himself from his conventional method of measuring his environment "in situ." Instead of placing countless direct sensors into the atmosphere and its boundaries, the time is approaching when a small number of orbiting space observatories may be able to do the same job, but remotely. This possibility is of revolutionary significance for operational services and deserves to be developed vigorously.

Third, computer technology is rapidly moving towards the point when it will be able to handle the mass of data to be transmitted from space to ground, and to process and disseminate the analyzed product to the user in real time and in the needed format.

Fourth, mathematical modeling of the atmosphere and the oceans, has advanced to the point where our understanding of the physical processes is greatly enhanced and where computer analysis and prediction of our environment is primarily limited by the available global data input.

Looking into the future, it appears that these developments will dovetail in a few years to offer the environmental sciences a unique global tool. The lead time is short, and planning must start now to arrive at an integrated space-ground system able to apply the expected data flow with maximum efficiency at all user levels. The development efforts on ground systems must parallel the space effort, if we are to capitalize on our total national space investment.

1.2 "ENVIRONMENTAL SCIENCES" AND ESSA PROGRAMS

The term "Environmental Sciences" has only recently become prominent as a meaningful collection of disciplines. In the context of this report it deserves some explanation. The concept of the environmental sciences considers the geophysical environment of man's total activities—ranging from the

Table 1.2-A — Programs of the Environmental Science Services Administration

I. ENVIRONMENTAL SERVICES

Weather and Ocean Forecasts and Warning Services

- Public weather and warning
  - Public weather forecasting
  - Hurricane and tornado
  - Air pollution
- Special weather
  - Fire weather
  - Agriculture weather
  - Aviation weather
  - Space operations weather support
- Marine environmental predictions
  - Marine weather
  - Ocean forecasting
  - Tsunami warning
- Basic weather
  - Observations network
  - Communications network
  - Analysis and prediction

River and Flood Prediction and Warning Services

Earth Description, Mapping and Charting Services

- Geophysical
  - Geodesy
  - Geomagnetism
  - Seismology
- Aeronautical charting

Marine Description, Mapping and Charting Services

Telecommunications and Space Services

1. Telecommunications
2. Space "Weather" Forecasting

Environmental Satellite Services

Environmental Data Services

II. ENVIRONMENTAL RESEARCH*

Institute for Earth Sciences

- Geomagnetism Laboratory
- Earthquake Mechanisms Laboratory
- Geodetic Laboratory

Institute for Oceanography

- Physical Oceanography Laboratory
- Land and Sea Interaction Laboratory
- Marine Geology and Geophysics Laboratory
- Pacific Oceanographic Laboratory
- Sea-Air Interaction Laboratory

Institute for Atmospheric Sciences

- Atmospheric Physics and Chemistry Laboratory
- Air Resources Laboratory
- Geophysical Fluid Dynamics Laboratory
- National Hurricane Research Laboratory
- Research Flight Facility
- National Severe Storms Laboratory
- Atmospheric Turbulence and Diffusion Laboratory

Institute for Telecommunication Sciences and Aeronomy

- Ionospheric Telecommunications Laboratory
- Tropospheric Telecommunications Laboratory
- Space Disturbances Laboratory
- Aeronomy Laboratory
- Tropospheric Wave Propagation Laboratory

*The research organization of ESSA noted in this table was recently re-structured to remove the Institute level. However, the laboratories listed are still representative of ESSA's research activities.

oceans and the solid earth through the atmosphere to space—as a scientific and operational entity. The Environmental Science Services Administration (ESSA) was formed to translate this multidisciplinary approach into actual programs. It is perhaps by the activities of this new agency that the substance of the environmental sciences can best be described.

ESSA—in the words of the President—is to serve as . . . "a single national focus to describe, understand, and predict the state of the oceans, the state of the upper and lower atmosphere, and the size and shape of the earth." Since its formation, ESSA has made a concerted effort to develop an integrated program for the environmental sciences. Its major services and areas of research efforts are listed in Table 1.2–A.

ESSA is primarily a *service* organization; therefore, the programs tabulated under I of the table are the core of its activities. These services covering the fields of Meteorology, Hydrology, Geophysics, Oceanography, Telecommunications and Space, Environmental Satellites and Environmental Data are primarily operational and are supported by ESSA's worldwide facilities.

The service functions are applied *research and development* activities in ESSA's major line components and in the Research Laboratories. The laboratories listed under II of Table 1.2–A give a better insight into ESSA's scientific activities than would an elaborate list of research projects. The interdisciplinary approach is advanced and emphasis is placed on the interfaces between earth, oceans, atmosphere and space. Not only are the boundaries and their interactions under study, but useful scientific methodologies and findings from one discipline are applied to others.

The service and research segments of ESSA pursue several *major program* areas which should be mentioned here because of their importance. The majority of them cross organizational and disciplinary boundaries.

The World Weather Program directed toward the implementation of the international "World Weather Watch" is concerned with complete global observation of atmosphere, earth and ocean surface.

The Weather Modification Program explores the physical possibilities to modify (and eventually control) such meteorological factors as precipitation, tropical storms, heat balance, local or large scale weather, and climate.

The Environmental Pollution Program is of obvious and increasing significance. The same is true for the Earthquake Reporting and Prediction Program. The Nationwide Natural Disaster Warning System is designed to protect the nation against the effects of catastrophic events such as tornadoes, floods, storm surges, and seismic sea waves.

The Marine Environmental Activities Program, concerned primarily with the Continental Shelf, employs the agency's capabilities in Geodesy, Oceanography and Hydrography.

In all programs, technical facilities such as computers, laboratories, ships, airplanes and satellites are utilized across the board wherever possible. Nearly all components of ESSA connected with the activities listed in Table 1.2–A have participated in the present report.

1.3 SPACE VEHICLE CAPABILITY – PRESENT AND FUTURE

In the beginning of this chapter the expectation was expressed that space technology, in combination with certain other technical developments, will advance the environmental sciences on a broad front. A short survey is given here on present and future space vehicles available to the environmental sciences.

Table 1.3–A lists spacecraft which presently carry, or are scheduled to carry, environmental

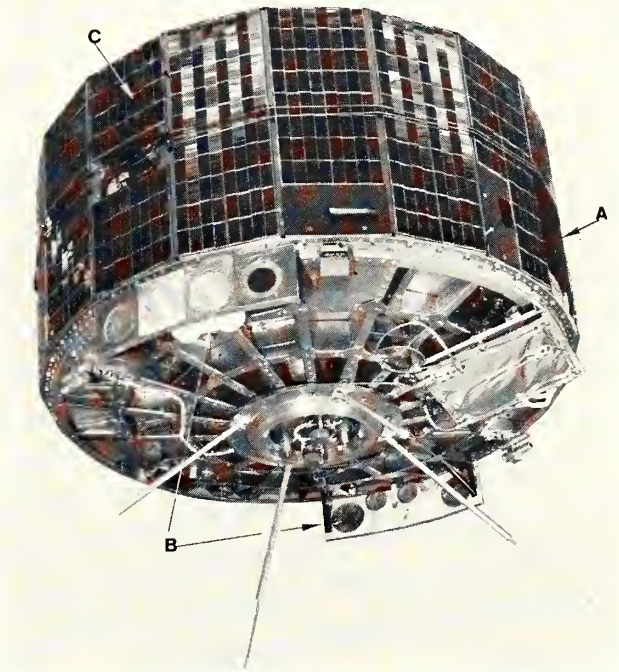

Figure 1.3-1. Operational Meteorological Satellite ESSA 3. (A) Advanced Vidicon Camera System-AVCS; (B) Flat Plate Radiometer; (C) Solar Cells.

Table 1.3-A – Spacecraft Supporting the Environmental Sciences (NASA/ESSA)

Discipline	Spacecraft		Functions
	Present	Future	
Earth Sciences	ECHO PAGEOS GEOS	GEOS	Geometric and gravimetric geodesy
Meteorology Hydrology Oceanography	TIROS ESSA (TOS) NIMBUS ATS GEMINI	NIMBUS TIROS-M IMPROVED TOS GOES# APOLLO	Cloud imaging Cloud and surface temp. (IR) Water vapor Temperature & water vapor profiles Heat budget Cloud top heights Ice/snow surveillance Interrogation/location (IRLS) Sferics Surface temperature (MW) Ozone
Aeronomy, Telecommunications and Space environment	OGO ALOUETTE EXPLORER ISIS	ISIS TIROS M IMPROVED TOS GOES# OGO ATS EXPLORER	Ionospheric radio beacon Topside sounding Solar x-ray Proton monitor Multiple solar monitoring

"GOES" (Geostationary Operational Environmental Satellite) proposed, but not yet approved.

experiments and which are monitored by ESSA scientists. The polar orbiting ESSA* (Environmental Survey Satellite) spacecraft (Figure 1.3–1) is being used operationally for meteorological purposes, while Nimbus is used as a large test platform for sensors which may later be included on these and other operational spacecraft. ECHO and PAGEOS are being used to make geodetic control measurements. Figure 1.3–2 shows a model of TIROS-M, the R&D prototype of the Improved TOS (I-TOS) spacecraft which will eventually become the operational ESSA satellite. Twice the weight and four times the volume of present operational satellites, TIROS M and I-TOS would combine on one satellite the sensor systems which now exist on two separate operational vehicles. With the additional weight and volume capacity of I-TOS, other systems may be added without major design changes.

Geo-stationary platforms such as those in the existing and proposed Application Technology Satellite (ATS) and the proposed Geo-stationary Operational Environmental Satellite (GOES – see Figure 1.3–3) series are designed to carry high resolution scanning cameras (to follow rapid movements in the atmosphere) as well as data collection and communications devices of direct interest to the environmental sciences.

ESSA scientists, working in conjunction with other experimenters, are also concerned with data acquired from Orbiting Geophysical Observatories (OGO), International Satellites for Ionospheric Studies (ISIS), ALOUETTE, EXPLORER and other ve-

*The ESSA spacecraft is part of the TIROS Operational Satellite (TOS) system.

hicles used to investigate the ionosphere and space environment.

Experiments on these and other spacecraft shown in Table 1.3–A are discussed more fully in the text (see especially *Related NASA Programs* at the end of each section in Chapter 2). There are, of course, other satellite programs in the offing with which ESSA would undoubtedly become involved once they have been approved, such as the proposed Earth Resources Survey (ERS) and Advanced Applications Geodetic Satellite (AAGS).

It is evident from this list that many components of ESSA are already deeply involved in space activities and are working in close collaboration with NASA.

The unmanned satellites available to the environmental scientist are either special purpose spacecraft such as TIROS and ALOUETTE or general purpose (observatory type) satellites, such as OGO and ATS*. In general, the total weight of earth orbiting special purpose satellites is presently between 100 and 500 lbs., while observatory satellites are in the 1,000 lbs. class, as dictated by the payload capability of the launch vehicles used. If the weights of power supplies and other spacecraft systems are excluded, the discretionary payload available for equipment for satellite experiments ("experiments payload") is generally about 20 percent of the total weight. Therefore, the experiments payload available on unmanned spacecraft rarely exceeds a few hundred pounds.

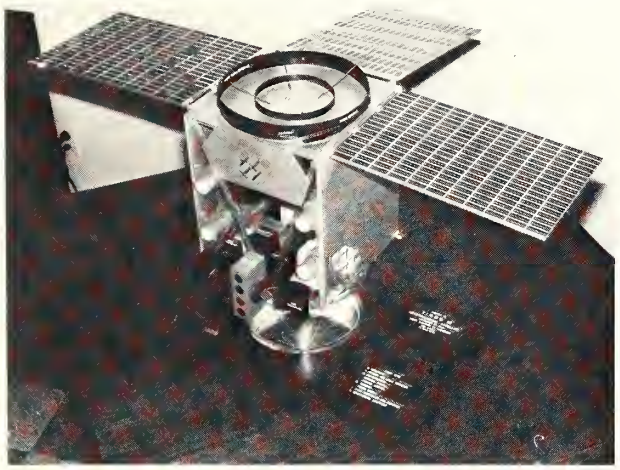

Figure 1.3-2. A model of TIROS M, the R&D prototype of the Improved TIROS Operational Satellite (I-TOS) series of ESSA spacecraft. Already under construction, TIROS M will be launched in early 1969 into a polar orbit. The spacecraft is being built under NASA contract, the sensors are being funded for by ESSA.

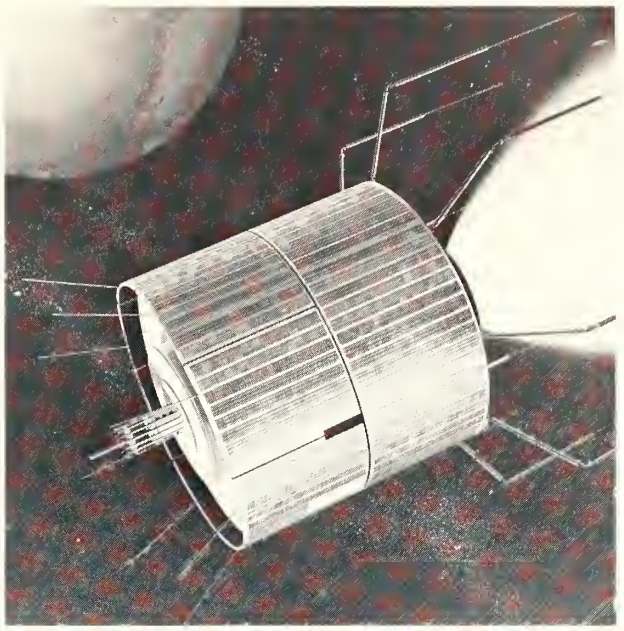

Figure 1.3-3. Artist's concept of the proposed Geostationary Operational Environmental Satellite (GOES). In a stationary orbit 22,000 miles above the earth, this type of ESSA satellite would carry sensors for continuous earth observation as well as systems for data collection and communication.

On manned spacecraft (Mercury, Gemini) the astronauts have conducted many scientific experiments, among them some environmental science experiments with ESSA scientists acting as experimentors or consultants. Examples are the "synoptic weather photography experiment" (NASA, 1967; also see Figure 2.4-8) and certain aeronomy experiments. The equipment used in these types of experiments is light and compact and the experiments plan is flexible so as not to interfere with the primary mission. The same will hold for the coming manned Apollo flights using Saturn launch vehicles.

The time, however, is approaching when Saturn-Apollo space vehicles may become available for flight missions other than the lunar landing mission. If these vehicles are used for primary scientific missions in earth orbit, the experiments carrying capability and power available on present satellites would be raised by at least an order of magnitude. This would permit a whole new look at possible environmental satellite systems, both in terms of instrumentation and crew participation.

Table 1.3–B shows the total payload weights of the two Saturn launch vehicles, the "uprated Saturn-

*For a definition of observatory type spacecraft, see Section 3.6.

Table 1.3-B – Payload Capability of Saturn-Apollo Space Vehicles

Launch Vehicle	Mission	Approx. Payload (lbs.)
Saturn I (Uprated)	Low Earth Orbit	38,000 to 40,000
Saturn V	Low Earth Orbit (2 Stage)	275,000 to 280,000
	Synchronous Earth Orbit (3 Stage)	67,000 to 68,000
	Lunar Flight (3 Stage to Escape Velocity)	95,000 to 100,000

I" and "Saturn-V." Their two-stage versions can inject payloads of approximately 40,000 and 280,000 lbs., respectively, into low earth orbit, while the 3 stage Saturn-V can carry nearly 70,000 lbs. into synchronous orbit, that is into a geostationary orbit of 19,350 n.m. over the equator. Figures 1.3-4 and 1.3-5 show the Saturn-V three stage launch vehicle and the Apollo spacecraft.

The experiments weights using modified Apollo hardware are listed in Table 1.3–C. Assuming that the Saturn-I will be used primarily for low earth orbit and the Saturn-V for synchronous orbit, the available experiments weights range from about 7,000 to 20,000 lbs. Available power will be in the 1 to 5 kilowatt range. These remarkable possibilities exist because a number of systems needed for the lunar landing can be eliminated and replaced for earth orbital applications. An example is the Lunar Module or "LM" (Figure 1.3-6), the descent stage of which can be replaced by an instrument carrier (Figure 1.3-7). In this way the Apollo spacecraft can be transformed into a manned laboratory, or "LM/LAB"; (see also Figures 3.6-5 and 3.6-6). The Command and Service Modules ("CSM") can likewise be used as instrument carriers. Both possibilities are listed in Table 1.3–C.

The "Apollo Applications Program" (AAP) also foresees an embryonic space station consisting of

Table 1.3-C – Experiment Weights (Excluding Power Supplies) Available on Saturn-Apollo Space Vehicles

Mission	Approximate Experiment Payload (lbs.)
SATURN I (Uprated)	
200 NM Earth Orbit; 4 to 8 weeks; 50 inclination or less	
Command and Service Module/Lab	9,000
LM/LAB	20,000
SATURN V	
Synchronous Orbit	
Equatorial 45 days	
LM/LAB	8,000
Inclined 14 days	
LM/LAB	7,000

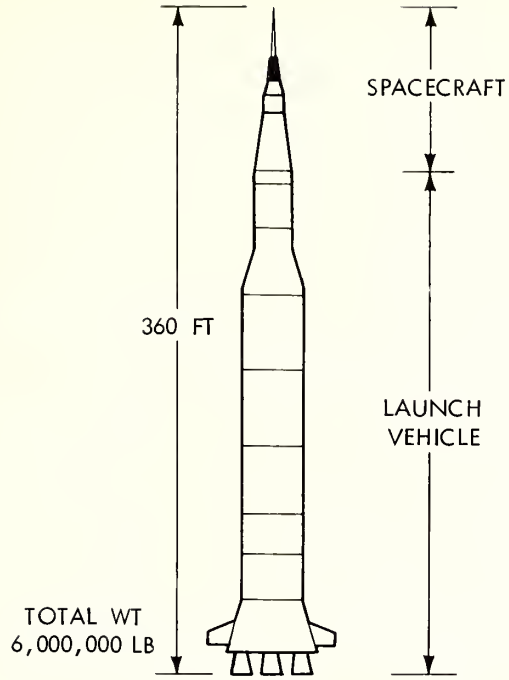

Figure 1.3-4. Saturn V launch vehicle with Apollo spacecraft.

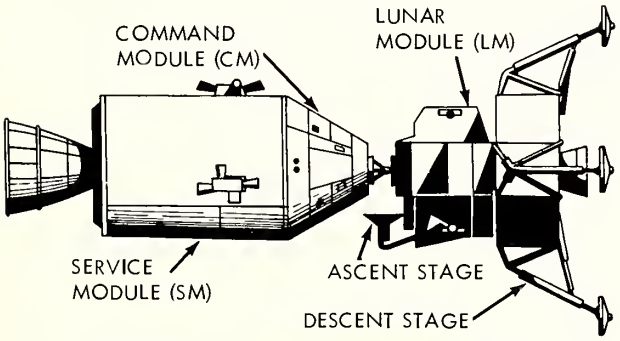

Figure 1.3-5. Apollo spacecraft, translunar flight configuration.

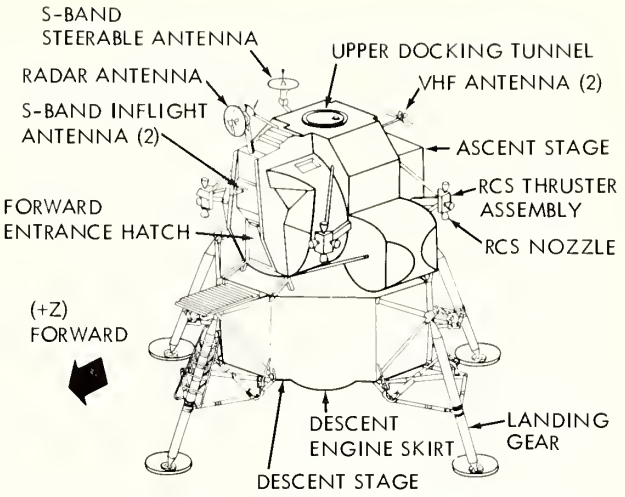

Figure 1.3-6. Lunar Module ("LM") of the Apollo spacecraft; lunar landing configuration.

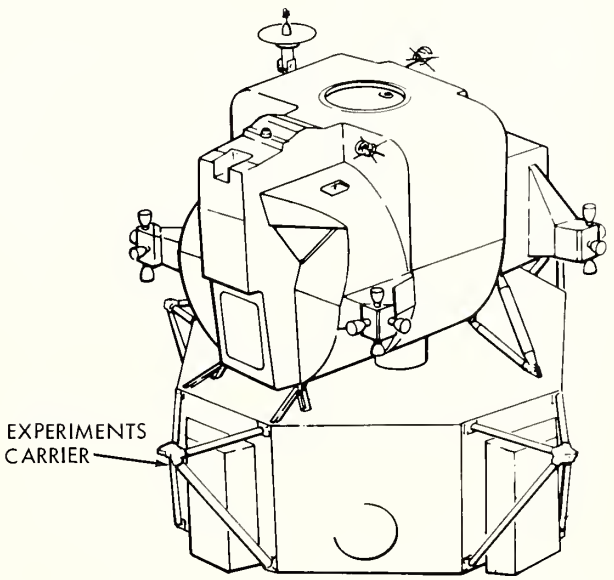

Figure 1.3-7. Modified lunar module (LM/LAB) for earth orbital applications.

modified Apollo modules connected by a Multiple Docking Adapter (MDA). This versatile "cluster," (Figure 1.3–8) will be assembled in orbit after two double launches and can be visited and resupplied by flight crews over a time span of 6 months to one year. In addition to a hangar like "Orbital Work Shop" (OWS) it will carry several modules of specific interest to the environmental sciences. One of them is an earth-oriented experiment carrier for the observation of atmosphere and natural resources, the other a sun-oriented telescope assembly, the so-called "ATM" or Apollo Telescope Mount, (Figure 1.3–9), which offers unprecedented research possibilities in the field of Space disturbances (Section 2.2).

During the early phases of a Saturn-Apollo applications program, flight time, inclination and orbital height will be limited. Typical parameters during this phase would be one to two months flight time, 50° inclination, and 200 n.m. altitude. Later, these values will go up and more desirable orbits can be flown. However, higher inclination and longer flight time will obviously reduce the payload which can be accommodated.

The parallel program of the Air Force, the MOL System, is likewise of interest to environmental research. It foresees a Manned Orbital Laboratory

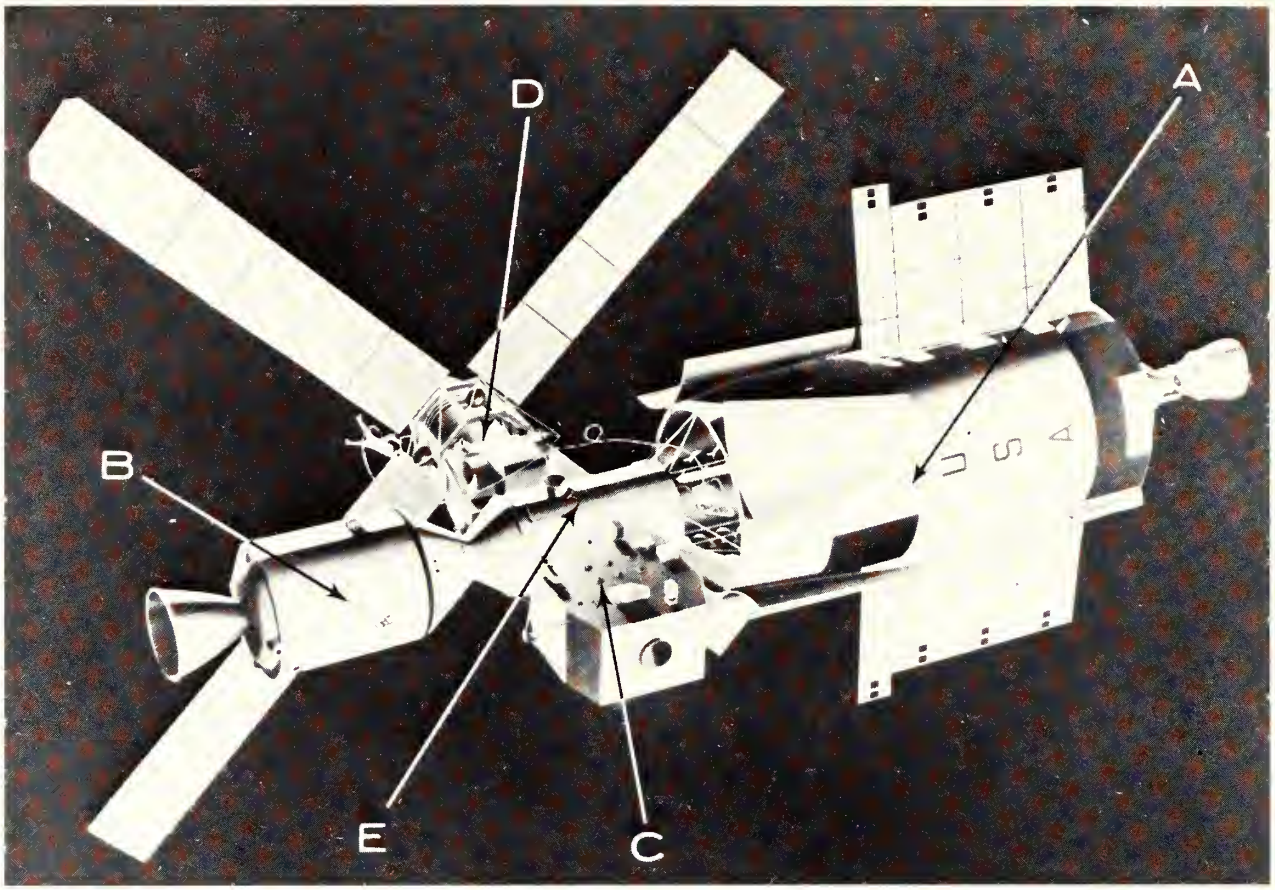

Figure 1.3-8. The "Cluster" of the Apollo Application Program. Docked into the Multiple Docking Adapter 1 (MDA) are the following modules: (A) Orbital Workshop (OWS), a spent Saturn stage; (B) Apollo Command and Service Module (CSM); (C) Application A and B Modules (AAP A/B), earth oriented for meteorology and natural resources; (D) Apollo Telescope Mount (ATM), sun oriented (See Fig. 1.3-9). The modules A and D carry solar panels An astronaut is seen outside the ATM.

(MOL) to be launched by a Titan-III booster into a low, possibly a polar orbit.

The new possibilities offered by manned scientific laboratories are taken into account in this study and their potential merits and drawbacks are discussed from a user standpoint.

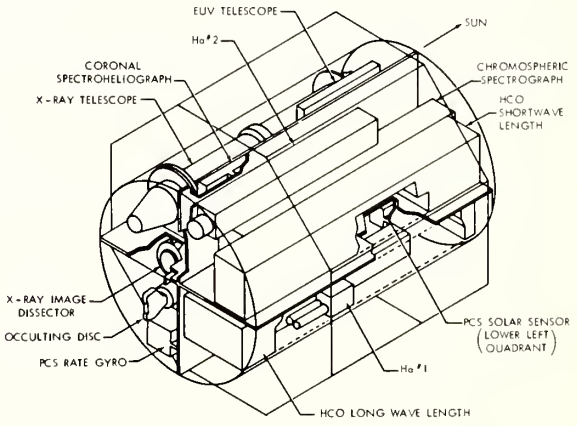

Figure 1.3-9. The solar telescope assembly of the Apollo Applications Program. ATM = Apollo Telescope Mount, EUV = Extreme Ultra Violet, PCS = Pointing Control System, HCO = Harvard College Observatory experiment.

chapter 2

PROPOSED ENVIRONMENTAL MEASUREMENTS from SPACE

2.1 GENERAL APPROACH

As mentioned in the introduction, the ESSA task force formed five ad-hoc panels, four covering certain scientific disciplines, the fifth panel dealing with the technical feasibility of the proposals.

The disciplinary panels were concerned with the following scientific areas: (1) Aeronomy, Telecommunication Sciences, and Space Disturbances, (2) Meteorology and Hydrology, (3) Oceanography and Hydrography, and (4) Earth Sciences. Each panel represented a cross section of the disciplines within ESSA, and the study is restricted intentionally to these disciplines. The fields covered by the panels are defined as follows:

"Aeronomy, Telecommunication Sciences, and Space Disturbances" deal with the physics of the upper atmosphere of the earth (and the planets), with tropospheric and ionospheric telecommunications, and with space radiation and solar disturbances, but not with space physics in general.

"Meteorology and Hydrology" involve atmospheric physics and the hydrological cycle, including short- and long-range weather forecasts; general circulation; hurricane and tornado warning service; aviation, marine, agriculture, and forest fire weather; river and lake forecasts; snow and ice, weather modification and air pollution, but not the biological aspects.

"Oceanography and Hydrography" cover the physics of the oceans and ocean beds, the continental shelves, beach morphology and estuaries, sea ice, sea state, storm surges and seismic waves, sea/land and sea/air interaction, but not marine biology.

Finally, "Earth Sciences" include geomagnetism, seismology, geometric and gravimetric geodesy (including photogrammetry), but not geography and geology.

Chairmen and members of the panels are listed in Appendix B.

The task force attempted to avoid a common fallacy of this type of study, namely to speculate on what application can be made of space vehicles assumed to be available. Instead the components of ESSA based their proposals on hard requirements that are within the defined missions of the Environmental Science Services Administration. It should be understood, however, that most proposals fulfill also the requirements of various other agencies and institutes in the same disciplines and that they should not be interpreted to represent ESSA's sole responsibility.

All proposals followed a "suggested approach" (see table 2.1-A). Over 150 suggestions were screened by the panels. In several cases, identical experiments were proposed by different sources for different reasons. This would not have been surpris-

ing if these sources were oriented toward either research or operations. It is interesting, however, that identical proposals came from entirely different disciplines. One example is the measurement of surface roughness by radar scatterometer techniques. Such an experiment is of interest (1) to the scientific and operational oceanographer for determining sea state, (2) to the meteorologist for obtaining information on ocean surface winds and on boundary layer characteristics over ground of different texture and vegetation, and (3) to the telecommunication expert for data on groundwave propagation. Another example is the observation of ice which has important aspects for (1) the meteorologist in regard to extended weather forecasting and climatological studies, (2) the hydrologist from a standpoint of water storage and river and flood control, and (3) the oceanographer in support of marine research and operations. Ice is, therefore, discussed under all three disciplines.

Table 2.1-A — Suggested Approach for Experiment Proposals

- Description of problem.
- Relation to ESSA mission.
- Current status of observations and limitations.
- Improvements desired.
- Specific data requirements.
  - Type of data
  - Area coverage
  - General surveillance or target of opportunity
  - Resolution desired (and useful limits)
    - Parameter resolution
    - Geometric resolution
      - Horizontal
      - Vertical
    - Time resolution
      - Lifetime of phenomena
      - Interval between observations
      - Duration
    - Real-time requirement?
- Ground or airborne observations desired.
- Proposed technical approach.
- Alternate possibilities.
- Crew contribution.
- Preferred orbit.
- Background material and references.
- Proposing specialist.

To screen the proposals a set of selection criteria was developed (Table 2.1-B) which served as a general guideline to the panels. While there was no stringent requirement that all criteria had to apply to each and every proposal, those selected and described in this report comply, in the opinion of the panel members, with the majority of the criteria.

While ESSA mission importance is listed first it was by no means the overriding consideration in selecting proposals. Some requirements were not given priority because certain important criteria, such as technical feasibility, were lacking. Others, already under development, were not elaborated on because they are well described in existing program documents. Emphasis was, therefore, given to new ideas and important concepts.

"Educated guesses" had to be applied to the technical feasibility of certain experiments; because proposals were projected ahead about 5 years, some optimism was justified when the basic concepts appeared to be sound. It appeared also reasonable to seriously consider experiments which fulfill multiple requirements or which have early flight opportunities on approved space missions. Regarding the principal investigator it was felt that the "man-behind-the-project" is a significant consideration, for, unless an overriding requirement exists, an idea is only as good as the proponent's willingness to pursue it actively. Special attention was given to manned space platforms. Finally, a comparison with conventional techniques, especially with airborne or ground based probes, was made in each case. As can be expected not all proposals survived the screening.

In the following section the different disciplines are surveyed with respect to their requirements. Some selected proposals are discussed in detail.

Table 2.1-B — Selection Criteria for Determining Requirement Priorities

- Importance to ESSA mission.
- Technical feasibility and hardware availability.
- Utilization of common instrumentation for multiple requirements.
- Practical flight opportunities, including schedule.
- Principal investigator available or programs in existence.
- Manned platform attractive from standpoint of weight, volume, shape, power and man's contribution.
- Superiority over conventional methods, including existing satellites.

2.2 SPACE DISTURBANCES

2.2.1 Description of Scientific Field Considered

The electrified nature of the earth's upper atmosphere results from bombardment by energetic photons (X-rays and ultraviolet light) and energetic charged particles (electrons and protons) emitted by the sun. Occasionally, and especially during those solar disturbances known as flares, major increases in the flux of these radiations occur. These outbursts result in major changes in the ionosphere having important (and often catastrophic) effects on ionospheric telecommunications. Because of the interaction between the charged particles and the earth's magnetic field these ionospheric effects are most pronounced in high magnetic (polar) latitudes.

Since 1942 ESSA'S Institute for Telecommunication Sciences and Aeronomy, and its predecessors, have been active in the study and forecasting of periods of solar activity and ionospheric disturbance. In recent years a greater urgency has been given to this forecasting by the radiation hazards involved in the man-in-space program (of the National Aeronautics and Space Administration and the Department of Defense) and in supersonic travel. Furthermore, disturbance forecasts are of value in unmanned space experimentation when special observations are required (e.g., firing sounding rockets into proton showers, the Lunar Orbiter Program, etc.).

To discharge successfully the responsibility assigned to it as the centralized "Space Weather" agency to serve the common needs of all agencies, the Space Disturbances Laboratory has been established within ESSA. This laboratory conducts research and provides services related to the monitoring and prediction of fluctuations in the radiation environment of the earth. The principal objective of the research is to improve our understanding of these disturbances, including the mechanisms responsible for producing them and their consequences on man's use of the upper atmosphere and space for practical purposes. Towards these ends, studies are undertaken in the following fields: solar activity; solar-terrestrial relations; the interaction of the solar wind and the earth's magnetosphere; magnetic storm theory; the interaction of solar protons and the upper atmosphere; trapped particle phenomena; auroral disturbance and ionospheric storms. The objective of the forecasting service is the provision of forecasts and data services in the general field of upper atmosphere and space environment disturbance. To accomplish this objective, a variety of forecasts are made on time scales ranging from several hours to several weeks ahead. Parameters for which forecasts are prepared include geomagnetic activity, solar radio noise flux, occurrence probability of solar flares and ionospheric radio propagation conditions. As a necessary adjunct to the forecasting program, a large amount of solar and geophysical data are collected and analyzed on a rapid basis. Relevant data are published periodically.

While the primary users of the space disturbance forecasts are the National Aeronautics and Space Administration (OGO, OSO, Lunar Orbiter, Apollo, etc.) and the Department of Defense, other recipients include: radio communications operators (noise bursts), the Federal Aviation Agency, the Atomic Energy Commission, the Bureau of Reclamation and power generation and distribution companies (earth currents).

The routine and continuous monitoring of important fluctuations in the earth's radiation environment is recognized as an important ESSA responsibility; most other space investigating groups are primarily interested in space research. The principal reason why satellite monitoring of solar protons and X-rays are needed involves the requirement for spectral information not presently obtainable from ground based observations. For example, in NASA's Apollo project there is a need to know the radiation flux above a dangerous threshold. Because the upper atmosphere is ionized by a wide spectrum of proton energies, detailed spectral information is extremely difficult to obtain from ionospheric radio observations.

2.2.2 Proposals and Related Requirements

2.2.2.1 Scope. For an effective warning service continuous monitoring of the sun is essential. Limitations to the ground-based solar observations are imposed by weather conditions, by geometry (angular position of the observer relative to the sun) and by atmospheric absorption of ultraviolet and X radiations emitted from solar flares.

Much can be done by ground based optical, radio noise and ionospheric radio measurements; however, the need for continuous coverage in time, quick reaction capabilities and some difficulties in fully calibrating radio propagation measurements clearly point the need for an operational satellite sensor input to the space disturbance monitoring and forecasting system. In the early stages of this work priority has been placed on obtaining satellite sensor data on those solar energy outputs which

fluctuate most violently under disturbed conditions. These are solar proton emissions, which also constitute the most significant radiation hazard to space and near space activities, and solar X-rays in the 0.5 - 50Å range. Satellite sensors capable of making these measurements are reasonably well developed and space qualified. The space disturbance monitoring system is already making the maximum possible use of existing NASA scientific satellite data, the output of the NRL Solrad satellites and the DOD Vela system. These satellites and their data systems however are not, with the possible exception of the Vela system, capable of providing continuous data on a time scale compatible with the use of the satellite data in the forecast center in parallel with the ground based data.

Several proposals are presented in Table 2.2-A roughly in descending order of priority. While proposals 1, 2 and 3 are strongly recommended, proposals 5, 6 and 7 represent what we consider conceptually possible. For example, proposal 5 might be carried out in connection with NASA's Sunblazer project. Proposals 6 and 7 are, at this stage, research orientated and the necessary data may eventually be forthcoming from other sources.

2.2.2.2 An Operational Space Disturbance Monitoring System.

A. Initial Polar Orbiting Monitors

As a first step towards the realization of an effective and economical satellite sensor compatible with the requirements of a space disturbance monitoring system it is proposed to add space disturbance sensors to the ESSA Weather Satellite system operated by the National Environmental Satellite Center (NESC). The meteorological requirements necessitate the provision of on-line data transmission and processing systems which can take the data from the tracking station and make it available for use in a few tens of minutes. The data required for space disturbance forecasting represents only a small fraction of the meteorological data load produced by the present polar orbiting TOS (TIROS Operational Satellite)

Table 2.2-A — Proposals for Space Disturbance Monitoring

Proposal Number	Measurement	Orbit	Status and Comments
*1#	Solar Proton Monitor 0.1 — 60 Mev	Polar	Should fly on TOS 1969
*2#	Solar X-ray Monitor 0.5 — 60 A	Polar	Proposal in advanced stage for TOS 1970
*3#	Solar X-ray and UV Monitor, Solar Proton Monitor, Solar Radio Noise Monitor	Geostationary	Instrumentation under study.
4	Solar radiation and particles	Far earth 10^5 Km	Avoids radiation background problems and gives good real time data coverage
5	Far-side solar observations	Solar	Observe solar flares on far side for predictions.
6	Magnetospheric boundary and solar wind	Highly eccentric	Observe particles, magnetic field.
7	Solar gamma-ray monitoring	Polar or synchronous	Theory indicates possibility of solar gamma-rays.

Requirements of major importance * Proposals selected for detailed discussion.

system. It was therefore both convenient and logical to add space disturbance monitoring to the functions of the TOS system and in the long term to expand within the framework of an ESSA operational environmental satellite system which would be common to all those environmental measurements required on an operational basis.

The alternative possibility of using specially designed small satellites which could work through the ESSA tracking network has also been studied. This comparative study has shown that the addition of sensors to the TOS satellite is generally more advantageous for solar proton monitoring. A relatively low polar orbit is necessary for adequate sampling because solar protons are deflected to the polar regions by interaction with the earth's magnetic field. An alternative is a monitor outside the magnetosphere.

For solar electromagnetic radiation monitoring the choice between TOS and a purpose built satellite is not so clear. At least for short periods of a few months a special purpose satellite could be maintained in a sun synchronous orbit along the dawn-dusk line so that it can get an uninterrupted view of the sun. In contrast TOS, which is also sun synchronous but at 45° to the dawn-dusk line, is occulted by the earth for about 50 percent of each orbit. However, this disadvantage is somewhat mitigated by the fact that there is a good probability of several TOS vehicles being in orbit simultaneously. The orbit of TOS passes through the lower edge of the trapped radiation belts whereas a purpose built satellite could orbit below these. The radiation environment of TOS is high enough to pose difficult, although not insurmountable, screening problems in the design of radiation sensors. For the immediate future, it is judged considerably more cost effective to have space disturbance monitors carried as secondary sensors on the TOS system rather than using special purpose satellites.

A solar proton monitor for improved TOS has been approved and should start operation in 1969. This will cover proton energies from 0.1 to over 60 Mev in 12 channels. An energetic electron channel (for energies above 250 Kev) is also included to assist in delineating the boundary between the trapped radiation zone and the polar cap.

Of the various parts of the electromagnetic spectrum, ranging from gamma rays through radio noise emissions, solar X-rays in the approximate wavelength range from 0.5Å to 50Å are the most important from the point of view of space disturbance. At present monitoring of solar X-rays in the range from about 1Å to about 60Å is carried out by interrogation of the Naval Research Laboratories' Solrad satellite. This satellite is, however, inadequate for the monitoring system and it is proposed to add a suitable X-ray monitor to the TOS vehicles from 1970 onwards.

B. Future Monitoring System

While for practical reasons, the TOS monitor program outlined above will be used initially, there are other orbits which are more advantageous. The first is the polar orbit sun-synchronous along the dawn-dusk line. This gives a view of the sun at all times for solar radiation monitoring as well as being well suited to solar proton measurement. This has already been mentioned because of its compatibility with the existing ESSA tracking network. It has not received much attention recently because it was judged less cost effective than the use of standard TOS vehicles.

One orbit which has received much attention is the geostationary orbit since it seems likely that many of ESSA's operational requirements could be met by a geostationary satellite system. The advantages of space disturbance monitoring from a geostationary satellite are two fold. Firstly, in common with many other applications, the possibility of continuous real time data transmission to the ground would be a tremendous advantage in providing the forecast center with satellite sensor data immediately in parallel with ground based observations. Secondly, the satellite is occulted by the earth for only about 110 minutes per day and two satellites suitably spaced can easily provide continuous data on solar electromagnetic radiation. The disadvantages are that the radiation environment at geostationary altitude is at least equally troublesome as that of TOS and the position of the satellite in the magnetosphere imposes a high and uncertain energy cut off in solar proton measurements. However, it is certain that the protons with energies of 140 Mev and above, which are of most concern to supersonic transport operations, could be reliably detected and the information made available on the ground without the delays inherent in a polar orbiting satellite system. Studies are in progress to define subsystems compatible with likely ESSA geostationary satellites for solar proton and X-ray monitoring.

The measurement of centimetric solar radio noise is a well established method of determining both the general background level of activity and flare events. Although ground based measurements are satisfac-

tory it becomes expensive in communication links to provide 24 hour real time coverage at one point. It might be cheaper and more effective to instrument a pair of geostationary satellites for this measurement and receive the data directly at the ground stations requiring the data.

Other orbits which have future possibilities are: (1) the far earth orbit, i.e. at 10^5 km and beyond, which is used by the Vela system and avoids problems associated with operation inside the trapped radiation zone and (2) the solar orbit, which permits a view of the far side of the sun. The latter observations could become important in long term forecasting since they permit observations of the active regions as they rotate about the far side of the sun.

2.2.2.3 Proposals for Future Consideration. The evolution of the space disturbance monitoring and forecasting program depends on a better understanding of (1) the interaction of solar particles with the geomagnetic field and (2) the development of solar active regions. Improvements in the input data to the forecasting system can be achieved by an expended observational program. To these ends the following proposals are advanced for future consideration. The technical feasibility of these proposals has not been examined in detail.

A. Far-Side Solar Observations

The prediction of solar flares and their associated disturbances is dependent on a knowledge of the location of active solar regions. The accuracy of such predictions could be enhanced by means of observations on the side of the sun which is not visible from earth. One way to accomplish this mission is to use three solar-orbiting satellites whose orbits are such that the far side is always visible, to at least one satellite, while another is in a position to relay the telemetered information to earth.

B. Magnetosphere Boundary and Solar Wind Studies

Predictions of the effects of solar particle-induced geophysical disturbances depend on a comprehensive knowledge of the magnetosphere, including its boundary, tail region, and associated shock front. Detailed calculations for these regions involve parameters such as solar-wind particle density, velocity, and temperature, as well as the interplanetary magnetic field in the boundary region. Acceleration mechanisms in the magnetosphere tail are supposed to cause a number of phenomena, such as aurorae and ionospheric absorption, which are observed on the earth. This region is not well understood, nor is it well defined.

In order to compute the interaction of the solar wind with the magnetosphere, resulting in various effects in the earth's vicinity, a detailed study of the parameters involved is needed. The aforementioned parameters should be measured in the magnetospheric boundary, shock front, and tail regions. Also, some determinations are needed within the magnetosphere and in interplanetary space.

C. Solar Gamma-Ray Monitoring

Theory indicates gamma-rays may accompany the occurrence of solar flares. These solar gamma-rays may be detectable by satellites outside of earth's atmosphere providing an advance indication of the proton energy to be expected. Also, this study could lead to basic deductions with respect to the acceleration mechanisms of solar flares.

2.2.3 Related NASA Programs

The knowledge of solar-geophysical relations which forms the basis for the space disturbance program has been derived in large measure from exploratory research programs carried out by NASA and the Department of Defense. For example, the earth's magnetosphere is known to have a key role in determining whether or not energetic particles from solar flares can reach the earth, and the structure of the magnetosphere has been studied by a number of satellites such as the Orbiting Geophysical Observatories (OGO) and the Interplanetary Monitoring Platform (IMP) series.

The Orbiting Solar Observatory (OSO) satellites and the NRL Solrad satellite have provided data on radiation in different parts of the solar spectrum. The observatory-class satellites have been able to make simultaneous measurements of different features providing correlation of geophysical phenomena.

A continuing research program is planned to improve the understanding of the complex interrelations involved in the field of space disturbances and how conditions change during the solar activity cycle. Among the spacecraft and sensors relating to space disturbances are:

Orbiting Solar Observatory (OSO) E, F, and G (1967-1970)

Instrumentation	Application
Crystal spectrometers, proportional counters, Geiger counters, ionization chambers	Solar X-ray spectrum, X-ray flares, X-ray background
Scanning spectrometer	Solar UV spectrum
Crystal scintillators	Energetic charged particles
Grating spectrometer	Solar UV radiation
Scintillation counter	Gamma radiation
Spectroheliograph	Extreme solar UV

Pioneer C, D, and E (1967-1969)

Instrumentation	Application
Magnetometer	Interplanetary magnetic field
Plasma probe	Interplanetary charged particles
Radio receivers/transmitters	Total electron content between earth and spacecraft
High energy particle detectors	Cosmic radiation

Interplanetary Monitoring Platform (IMP) E, F, and G (1967-1969)

Instrumentation	Application
Magnetometers	Magnetospheric and interplanetary vector magnetic fields
Particle counters and analyzer	Particle fluxes, spectra, solar effects (various energy ranges)

NRL/NASA Solar Explorer B (1967)

Instrumentation	Application
X-ray photometer	Solar X-ray and Lyman alpha (UV) radiation
X-ray counters	Solar flare X-ray spectra

2.3 AERONOMY AND TELECOMMUNICATIONS

2.3.1 Description of Scientific Field Considered

Electromagnetic propagation research and services provide vital support to telecommunications in the United States. The importance of this support cannot be slighted when one considers the $20 billion per year expenditure of this industry. The earth's surface and atmosphere have many effects on such waves; one aim of ESSA is to be able to predict these effects quantitatively so that the maximum possible benefit can be derived by the public from the investment in electromagnetic telecommunications systems. It is also important that the available electromagnetic spectrum be used with maximum effectiveness and efficiency. As the federal agency with the responsibility for propagation research and services, ESSA, through its Institute for Telecommunication Sciences and Aeronomy, assists in collecting and disseminating information on the distortion and attenuations experienced by the waves as they travel from a transmitter to a receiver. The pertinent electromagnetic spectrum extends in frequency from about 10^3 to about 10^{15} c.p.s., and distances range from tens of meters to intercontinental or even interplanetary distances. The propagation media include the atmosphere at all heights, the earth's surface and subsurface over wide geographical and climatic conditions, and space. This work is important in such areas as defense, aviation, navigation, public safety, public communications, entertainment, and space research.

The *science of aeronomy* is the study of the physical and chemical processes in the upper atmosphere, dominated by the presence of ionization. Aeronomy is important to a better understanding of the ionospheric propagation of radio waves; for example, the movements of the ionosphere produce signal fading. The electron density distribution in the ionosphere is determined to a large extent by the chemistry of the upper atmosphere. The interaction or coupling between the lower atmosphere and the ionosphere and between the outer atmosphere (magnetosphere) and the ionosphere exert a considerable influence on ionospheric phenomena. The ionosphere presents a unique plasma laboratory with no boundaries, a factor which limits many laboratory investigations. Aeronomy also includes studies of aurora, electron and ion temperatures, neutral and ion densities, and natural electromagnetic signals generated in the ionized medium.

Tropospheric radio propagation is affected by oxygen and by certain trace constituents such as water vapor, carbon dioxide and ozone. The influence of these constituents is particularly important because they absorb waves in certain frequency bands; for example, near 22.5 Gc/s (water vapor) and 60 Gc/s (oxygen). In addition to absorption, waves are attenuated or scattered by clouds, hail, and rain, particularly on frequencies greater than 3 Gc/s. Thus, the climatology of a geographical region is of importance in radio propagation and in the propagation of optical waves.

Propagation of these waves is also affected by the temperature profile which can produce ducts that trap energy and give rise to abnormally high signals at some receiving sites. Because of the decrease of the refractive index with height near the ground, radio beams are refracted generally toward the ground. However, because the atmosphere is an inhomogenous medium which changes slightly from one place to another at a given time and changes with time at a given place, a radio-wave beam will move about its average position. At a receiver, the amplitude and phase of the signal will fluctuate in a random manner as in the twinkling of a star. This scintillation is equivalent to the introduction of noise into a communications channel, and sets a threshold value on the required transmitter power. Furthermore, the phase fluctations set a lower limit to the accuracy with which radar techniques can measure distances.

In order to predict the behavior of radio waves propagating through the lower atmosphere, some knowledge of the average conditions which exist over the path, together with information on the long– and short-term variations is needed.

Turning now to *ionospheric propagation*, the properties of the D region (70-90 km) as it affects radio propagation must be considered. The primary important effects are: (1) the reflection of the very-long waves (10-30 Kc/s) and long waves (30-300 Kc/s), (2) the absorption of medium- and high-frequency radio waves, (3) the partial reflection of medium- and high-frequency radio waves, and (4) the scattering of very-high frequency waves (30-300 Mc/s) by irregularities.

To determine these effects quantitatively, it is necessary to know the height distributions of electron and ion densities and of electron collision frequencies, and the horizontal and temporal variations in these parameters. The sizes and velocities of irregularities are needed to determine the fading characteristics of reflected signals. Because of experimental difficulties in observing the D region and because of the complicated chemical and aerodynamical phenomena which occur there, scientific

understanding of the D region is probably not as extensive as that of the rest of the ionosphere.

The E (90-150 km) and F (150 km and above) regions of the ionosphere are of importance in long-distance propagation of high-frequency (3-30 Mc/s) and medium-frequency (300-3000 Kc/s) waves. The major limiting factor in the usefulness of these frequency bands is the ionospheric absorption at the lower frequencies and the penetration of the ionosphere at the upper end of the range. Intense absorption occurs sporadically near the visual auroral zones and over the polar caps. Knowledge of the location of these areas, together with a measure of the intensity of the absorption, is desirable.

At the upper end of the band, the frequency limit is determined by the height and maximum electron density in the ionosphere, and by the propagation path. From the point of view of telecommunications the uppermost layer, the F_2 layer, is the most important but, unfortunately, it is highly variable both geographically and temporally.

Because the ionosphere varies from hour to hour and from day to day, it is necessary to have a knowledge of this variability in order to select the optimum frequency, required transmitter power, antenna configuration, etc.

For short-term predictions, hour-by-hour information of the morphology of the ionosphere is needed, in a manner analogous to weather forecasting needs. A network of sounding stations exists over the world, but problems of data scaling, transmitting, and processing limit the development of this type of prediction.

Long-term predictions have been routine for a number of years. ESSA and similar organizations or laboratories in other countries issue ionospheric maps indicating the worldwide distribution of monthly median F_2 layer parameters for various hours of the day. While these maps have been, and are, of inestimable value in radio communications, they suffer because of the uneven geographic distribution of the input data.

Recently, methods for preparing these maps have undergone a revolutionary change with the development of numerical (computer) mapping. With this technique, there is a distinct need for a similar updating of the methods for collecting and scaling the raw data. Up to now, mapping has been confined to such parameters as the vertical penetration frequency and factors related to the height of the ionosphere. However, there is a need to extend the mapping to include areas of high ionospheric absorption (which determine signal strength, signal-to-noise ratio, etc.), areas of spread-F (which is related to the fading of radio waves), areas of sporadic E, and areas of total electron content.

A somewhat different problem which faces any communicator is the problem of *radio noise and interference.* Noise originates in several sources that are manmade or natural. Manmade noise originates mostly in electrical machinery (appliances, automobiles, and industry) and often consists of large-amplitude, short-lived spikes. Natural noise is of the thermal type (e.g. receiver noise, galactic noise, etc.) or of the burst-type (originates in the sun and in thunderstorms). The latter source is significant at very low frequencies but the noise power diminishes with increasing frequency. An important consideration of noise power is that thermal noise power is proportional to bandwidth, whereas with impulsive noise, the dependence of noise power on bandwidth is not known, *a priori.*

2.3.2 Proposals and Related Requirements

2.3.2.1 Scope. Studies involving radiowave propagation in the troposphere, ionosphere, and exosphere, and those having to do with the phenomena of aeronomy (aurora, radiation from charged particles, ionospheric effects, etc.) embody a large number of specialized disciplines. An understanding of the physics and chemistry of the upper atmosphere, and earth's magnetic field, charged particle behavior, the structure of the magnetosphere, and the solar wind is crucial to our ability to solve various problems of telecommunications. Satellite sensors provide some advantages over the traditional ground station observations because they can make *in situ* measurements in the regions of interest. The extent of ESSA's interest in the use of such sensors is indicated by Table 2.3–A in which some of the various possible experiments are listed.

2.3.2.2 Studies of the Lower Ionospheric Regions. The altitude region between approximately 50 and 150 km has been, for many years, of interest to aeronomists yet it has been and continues to be one of the more difficult of the atmospheric regions in which to make measurements. Radio ionosonde probing of the lower part of this region, for instance, tends to be unsatisfactory because of the large amount of absorption of the waves reflecting on the lower ionosphere. These regions are inaccessible to balloons while the lifetime of orbiting satellites in these regions is too short for economic use. Studies of this region, then, may depend very much on the use of ballistic vehicles; cannon-launched projectiles, rockets, and retrofired rockets launched from satellites.

Table 2.3-A—List of Proposals for Aeronomy and Telecommunications

Proposal Number	Descriptions	Special Orbits	Comments
	Priority Experiments		
*1#	Studies of the lower ionospheric regions	Polar desirable	See section 2.3.2.2
	(A) Ionospheric currents		
	(B) Ionospheric molecular constituents		
*2#	Ionospheric mapping	Polar	See section 2.3.2.3
	(A) Topside sounding		Versatile ionospheric satellite sounder
	(B) Ionospheric resonances		Obtain electron density magnetic field strength. Use topside sounders.
	(C) Irregularities		
	(D) Landau damping		
*3#	Noise mapping	Vicinity of 300 km, polar	See section 2.3.2.4
4	Proposals for Future Considerations		See section 2.3.2.5
	(A) Satellite plasma sheath studies	Ionospheric heights	
	(B) Charged particles (magnetosphere) and VLF emissions	Highly eccentric and synchronous	Relate charged particles to VLF emissions.
	(C) Ionospheric electric fields	Ionospheric heights, polar	Eject ionized chemicals
	(D) Trace constituents in the upper atmosphere	Low altitude (300 km)	Use infrared absorption techniques.
	(E) Electron densities	Synchronous	Use whistlers.
	(F) Magnetospheric conjugate point studies	Synchronous (75°W)	Study particles, VLF emissions, relate to ground observations.
	(G) Electron density in the Ci-Lunar medium	Moonbase	Receive on Earth, Moon-beacon transmissions.
	(H) Martian atmosphere studies	Mars fly-by	Absorption of solar radiation during dawn/dusk.
	(J) Infrared sensing of the lower atmosphere	Polar 300 km	
	(K) Millimeter wave sensing of the lower atmosphere	Polar 300 km	
	(L) Chemical releases from manned spacecraft	During reentry phase	To prevent reentry blackout
	(M) Electromagnetic properties of the Earth's surface	Polar	
	(N) Information capacity of satellite-ground links		
	(P) Optical communications		

#Requirements of major importance. *Proposals selected for detailed discussion.

A. Ionospheric Currents

One important class of phenomena occurring in this region is known as ionospheric currents. These currents, which flow in the conductive ionosphere, are of various types: the dynamo current, the solar disturbance currents, the auroral zone currents, and the equatorial electrojet.

The dynamo, or solar quiet, current is produced by diurnal vertical motions, caused by thermal and tidal effects. The motions of the charged component in the atmosphere across the geomagnetic field lines cause a current flow in a manner similar to that of an electric dynamo. The horizontal current pattern produced by this effect tends to be fixed relative to the sun with the earth rotating below it. The conjuncture of the north and south current systems produces the current near the equator known as the equatorial electrojet.

The solar disturbance currents are produced by the precipitation of charged particles related to solar activity. They cause significant perturbations to the current system by producing electric fields and by local perturbations of the ionospheric conductivity. These effects are usually most important in the auroral zone resulting in the auroral zone current system.

The existence of these current systems are originally inferred from analyses of magnetic records. Spherical harmonic analysis of the field, as determined by a worldwide network of magnetic stations, allows the separation of the field into a part external to the earth and one internal. Such techniques are limited, however, in providing definition of the currents; it is not possible, for instance, to determine their distribution with height.

These currents are an important part of the total relationships existing between solar events and phenomena observed at the earth, such as ionospheric communications disruptions and magnetic disturbances. A complete understanding of these effects, and a host of other phenomena associated with particle events, will require a full definition of these current systems.

Studies to be made include measurements at various latitudes and during various times diurnally and seasonally. One important experiment would be to explore the variations of these currents during solar events and to relate these changes to the development and occurrence of other solar-geophysical phenomena.

Rocket-borne magnetometers [Davis, et al., 1965; Heppner, et al., 1958] have become important tools for the study of these currents. They provide vertical magnetic field profiles whose perturbations from the known geomagnetic fields yield estimates of ionospheric current intensity with height. While these experiments have provided certain isolated determinations, a more extensive program must be undertaken to obtain a gross "picture" of these current systems. A means of obtaining these data by use of experiment packages retrofired from a satellite is presented in sub-section C (Experimental Systems).

B. Ionospheric Molecular Constituents

Quantitative estimates of the photochemical reactions taking place in the ionosphere depend in part on quantitative knowledge of the molecular constituents in this region. Such reactions include the ionic rates of disassociation and recombination basic to theories involving the formation of the ionosphere. Measurements of these constituents and their spatial and temporal relations are required.

C. Experimental Systems

The various programs using rockets and high altitude gun-launched projectiles for study of the high atmospheric regions should be continued and, to a large degree, expanded. A comprehensive network of rocket sites in widely dispersed geographic regions should be established to be used by a coordinated rocket sounding program. These sites would be available for other types of rocket-borne observations as well.

The logistic, economic, and political problems would, however, impose limitations on the locations of the rocket launching sites. Thus, the capability to launch retrofired rockets from spacecraft would be a valuable supplement to this program. There are several unique advantages for such a system, in addition to the geographic factors mentioned above. A wide range of trajectories, depending on the decrease in velocity achieved during retrofire, are available to suit various types of mission requirements. If the parent spacecraft is manned, the countdown and launch can be accomplished independently of ground control stations which will enable flights at specific times, and in favorable locations, during solar flares for instance. There may be some advantage in the possibility of deploying several vehicles in quick succession to cover a large geographical area nearly simultaneously. For the mass spectrometer measurements, an advantage will accrue because the instruments will be stored in a space environment for a period of time during

which time outgassing can be accomplished thereby eliminating a source of contamination usually encountered in rocket-borne mass spectrometric observations.

The trajectory depends on the difference in velocity produced by the retro-rocket which in turn depends upon such practical considerations as allowed weight and g-forces to be tolerated by the instrumentation; also, the final velocity in the atmosphere should be minimized in order to minimize the burn-up altitude.

As an example, consider the parent satellite at an altitude 370 km (200 n. miles). The orbital velocity at this altitude is about 7.7 km/s. If the eject is decelerated to 2 km/s, it follows a trajectory of about 5 minutes duration through a horizontal distance of about 550 km. Its final velocity is about 3 km/sec. The trajectory obtained is shown plotted in

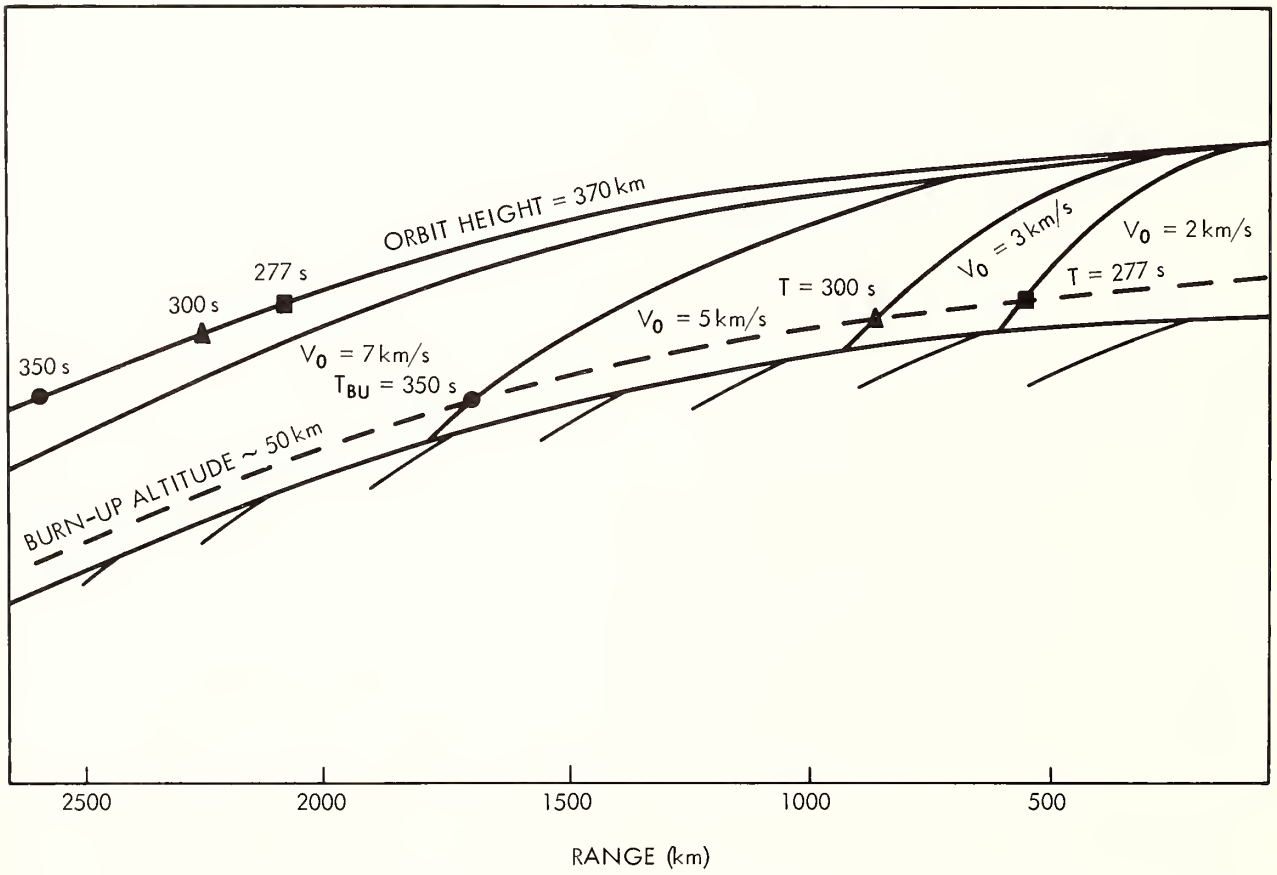

Figure 2.3-1. Various ejected vehicle trajectories.

Table 2.3-B — Ejected Vehicle Trajectory Parameters

Initial Velocity (V_0)	Time in Flight	Final Velocity	Eject Range	Parent Range	Separation
(km/s)	(sec)	(km/s)	(km)	(km)	(km)
7	656	7.4	4162	4590	428
5	350	5.5	1712	2625	913
3	300	3.9	880	2244	1364
2	277	3.2	550	2102	1552

Figure 2.3-1 which also shows the trajectories when the eject is decelerated to 3, 5, and 7 km/s. Table 2.3–B lists some of the parameters for these trajectories.

Data obtained may be telemetered to the ground or possibly to the parent satellite. In the case of the former, the positions of ejection are limited to the regions of existing ground telemetry stations. In the latter case, the trajectory must be selected such that the distance between parent and eject during the mission is small enough to allow effective telemetry.

This program, envisioned as incorporating a number of techniques including the traditional ground observation and ballastic vehicles, will provide a more complete understanding of this high atmospheric region from which we have, relative to higher and lower regions, very little data.

2.3.2.3 Ionospheric Mapping. By the term mapping we mean the determination of ionospheric parameters on a global scale. Such data are of great value both in the selection of optimum frequencies for ionospheric radio communications and in understanding the physics of the upper atmosphere. Most of our information of this nature comes from ground based soundings using the sweep-frequency radar or ionosonde [see Davies, 1965, Chapter 3]. From these soundings the world-wide distribution of electron density profiles can be obtained (subject to certain limitations) only for heights below the height of maximum electron density.

A. Topside Sounding; An Advanced Sounder

In order to probe above the electron density maximum, ionospheric sounders have been flown recently on satellites ALOUETTE I and II and EXPLORER XX. (While incoherent scatter sounders can provide profile data above the height of maximum density they cannot provide world-wide coverage because of the expensive installations). These satellites are flown at heights near 1,000 km. and probe downward to the electron density peak (Fig. 2.3-2). They measure the topside of the ionosphere and are known as "topside sounders."

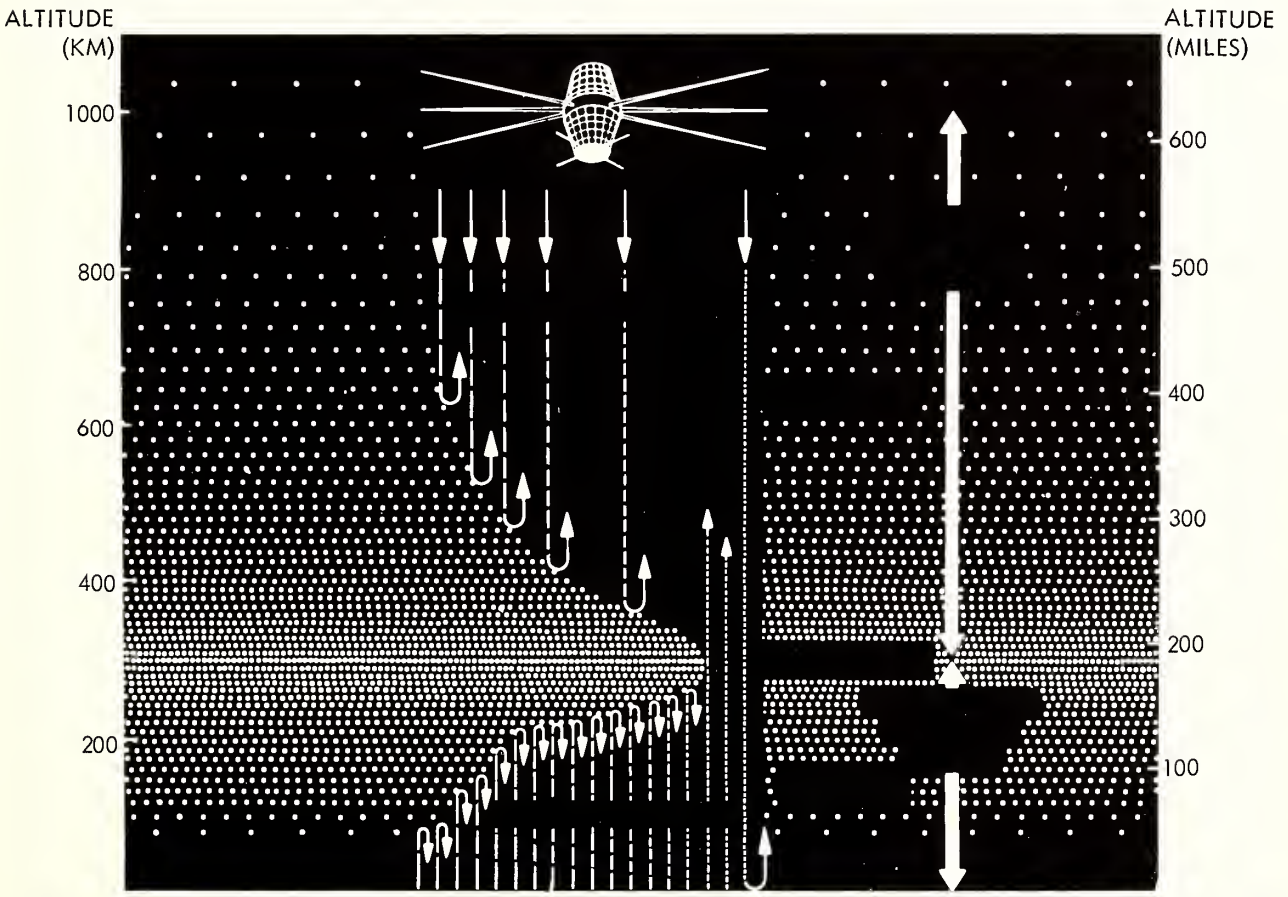

Figure 2.3-2. Ionospheric sounding techniques.

These sounders provide a means to map the topside ionosphere and have contributed to our knowledge of the ionosphere.

There is a need to utilize satellite sounders at low altitudes (200-300 km) in order to continue "mapping" the ionosphere for communications purposes and to study its physical processes to increase the theoretical understanding of this region. For such studies, the use of a highly flexible, computerized ionospheric sounder is suggested. Such an instrument can be used to study several phenomena concurrently and thus be of much greater value than a number of separate satellites each having a component of the sounder, although, it should be borne in mind that our main interest is in ionospheric sounding and that in some cases it may well be preferable to employ a number of simpler sounders to achieve the desired goal. For example, to map the F_2 layer critical frequency, one of the most important ionospheric characteristics for radio communication, it may be possible to use simple radio beacons on the ground and interrogate them with a satellite. However, the topside sounders ALOUETTE I and II have demonstrated their ability to measure the critical frequency to a relatively high degree of accuracy. We shall describe below a satellite sounder capable of supplying concurrently many required ionospheric data. This sounder could, conveniently, be developed with the joint U.S.–Canadian ISIS program (International Satellites for Ionospheric Studies).

The basic aim of the proposed advanced sounder is to exploit fully the capability of the radio-sounding technique in ionospheric and plasma studies. This capability has been proven by the ALOUETTE I, EXPLORER XX, and ALOUETTE II topside sounder satellites. In spite of the limitation of their specialized design (to measure vertical electron-density profiles *or* ionospheric irregularities), they are extraordinarily useful in a number of other measurements. For example, they have been used to measure accurately the local electron density and magnetic field, to study plasma resonances, and to monitor cosmic and solar radio noise.

The heart of the instrument will be a stored-program digital computer, the principal purpose of which is to control the sequence of operations on a very short time scale. In this manner, most of the sounder parameters, usually designed into the instrument, are established by the stored program and are completely flexible. The frequency, pulse length, repetition period, receiver sensitivity, etc., can be adjusted by command from the ground according to the particular measurement being performed. Among many other capabilities such an instrument could operate interchangeably in the sweep frequency (ALOUETTE) mode or in the fixed frequency (EXPLORER XX) mode.

The output data link for the instrument would also pass through the same computers. First, this may permit some immediate data processing during the periods between system-control actions by the computer. Second, it will permit feedback so that the data can influence the subsequent experimental parameters.

To perform a pulsed-sounder function, the instrument might operate as follows. The sounding frequency would be computed (incremented for swept-frequency, stepped for fixed-frequency, etc) and stored in the frequency-synthesizer register. The antenna would be switched to the transmitter, and the transmitter actuated. While the pulse is being transmitted, the relevant calibrations would be either transferred to the output or stored for later use. After a given number of computer cycles, the pulse would be terminated and the antenna switched to the receiver. For ionograms, the receiver output could be sampled periodically, calibration corrections applied, and then relayed to the output. For more sophisticated observations, certain kinds of echo pulses might be recognized and only their group delays, phase paths, or waveforms might be presented to the output. Finally, at the end of the receive period, a new frequency would be computed, and the cycle repeated.

Even for this specific function of the instrument, a great number of attractive variations are obvious. If swept, the frequency could sweep up, down, or in any other systematic fashion; or, it could be limited only to specific ranges of interest. It could be interlaced, pulse-by-pulse, with one or more fixed frequencies. The pulse length could vary with frequency or with the nature of the echoes obtained.

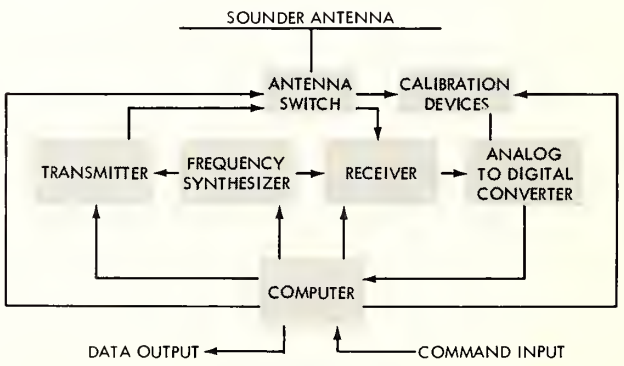

Figure 2.3-3. Block diagram of proposed satellite ionosphere sounder.

The output data could be some convenient function (such as logarithmic), independent of the detector characteristics. Data bandwidth could be conserved by telemetering only echo signals stronger than a given level, etc.

Figure 2.3-3 illustrates a possible configuration of the instrument. The command input and data output connect to an appropriate ground-line receiver and transmitter. The analog-to-digital converter converts the receiver output to a form compatible with the computer. The calibration devices measure such parameters as receiver sensitivity, transmitter power output, and antenna impedance.

The proposed instrument is well within the current state of the electronic art. None of the operational boxes in Figure 2.3-3 pose more than routine engineering problems. While further study is needed before the design specifications can be finalized, a few rough numbers might be useful. An adequate computer cycle time would be 2 microseconds. For functions like the topside sounders, this would permit 50 arithmetic operations within the pulse length; 10,000 within the receive period. Even with relatively simple computer logic, this is a large number of computations. The switching capabilities of the transmitter, synthesizer, etc., should be as fast as possible to approach 2 microseconds. For general ionospheric applications, the frequency capability desired is 0.1 to 30 Mc/s in 1 Kc/s steps. An adjustable power output from the transmitter of up to 100 watts (continuous) should suffice. A receiver dynamic range of more than 110 dB is needed, but it can be provided on various computer-selected channels. Both synchronous and amplitude detection should be incorporated in the receiver. Dipole antenna lengths of many tens of meters are needed; other antenna configurations should be contemplated.

B. Ionospheric Resonances

The equipment described in Section B can be used to study the properties of local plasma around the satellite. The transmitted radio signal excites resonant oscillations in the ambient plasma at frequencies which depend on the electron density and geomagnetic field. These resonant frequencies are known as the plasma frequency (f_N), cyclotron frequency (f_H), and hybrid frequency ($f_T^2 = f_N^2 + f_H^2$).

Measurements of these frequencies, to a part in 10^4 or 10^5, and the spectral widths of the f_N and f_T resonant lines can be made by sequencing observations between three characteristic frequencies: the cyclotron resonance (f_H), the x and z cutoffs, and the resonance under observation, exploiting the side-band structure of the cutoff and resonance frequencies as a vernier.

C. Irregularities

The same sounder can be used to determine the variation of electron density across magnetic field-aligned plasma irregularities. This variation, together with the ducting and scattering properties of the irregularities, can be determined by pulsing the sounder vary rapidly as it passes through the irregularities.

D. Landau Damping

Measurement of the dispersion and Landau damping of plasma waves would be accomplished using the receiver as a spectrum analyzer, with an auxiliary pulse source ejected from the satellite. An astronaut would vary the distance of the daughter-transmitter and the attitude of the satellite with respect to the geomagnetic field. The received electromagnetic and electrostatic waves would thus be recorded as a function of distance and of angle with respect to the geomagnetic field.

2.3.2.4 Noise and Interference Survey. Radio noise, both natural and manmade, places an unavoidable limit on the utility of a communications channel. Noise levels vary with time and geographic location, and noise maps are of great importance in the design of radio communication systems.

For many years, noise has been measured at ground-based stations, for which a vast worldwide network of stations is used to obtain the noise levels in various frequency bands. From such studies, world noise maps are produced; a typical example of such a map is shown in Figure 2.3-4.

A basic limitation of past noise monitoring techniques is that the results yield the noise in a given frequency band at a particular location received on an omnidirectional antenna. Since most radio applications utilize systems having directive gain, maps of noise sources rather than received noise are needed. The use of satellites with noise-source locating capability would have many advantages over ground based stations in providing such maps.

A. Objectives

The objectives of this proposal are to produce maps of the earth showing contours of noise and inter-

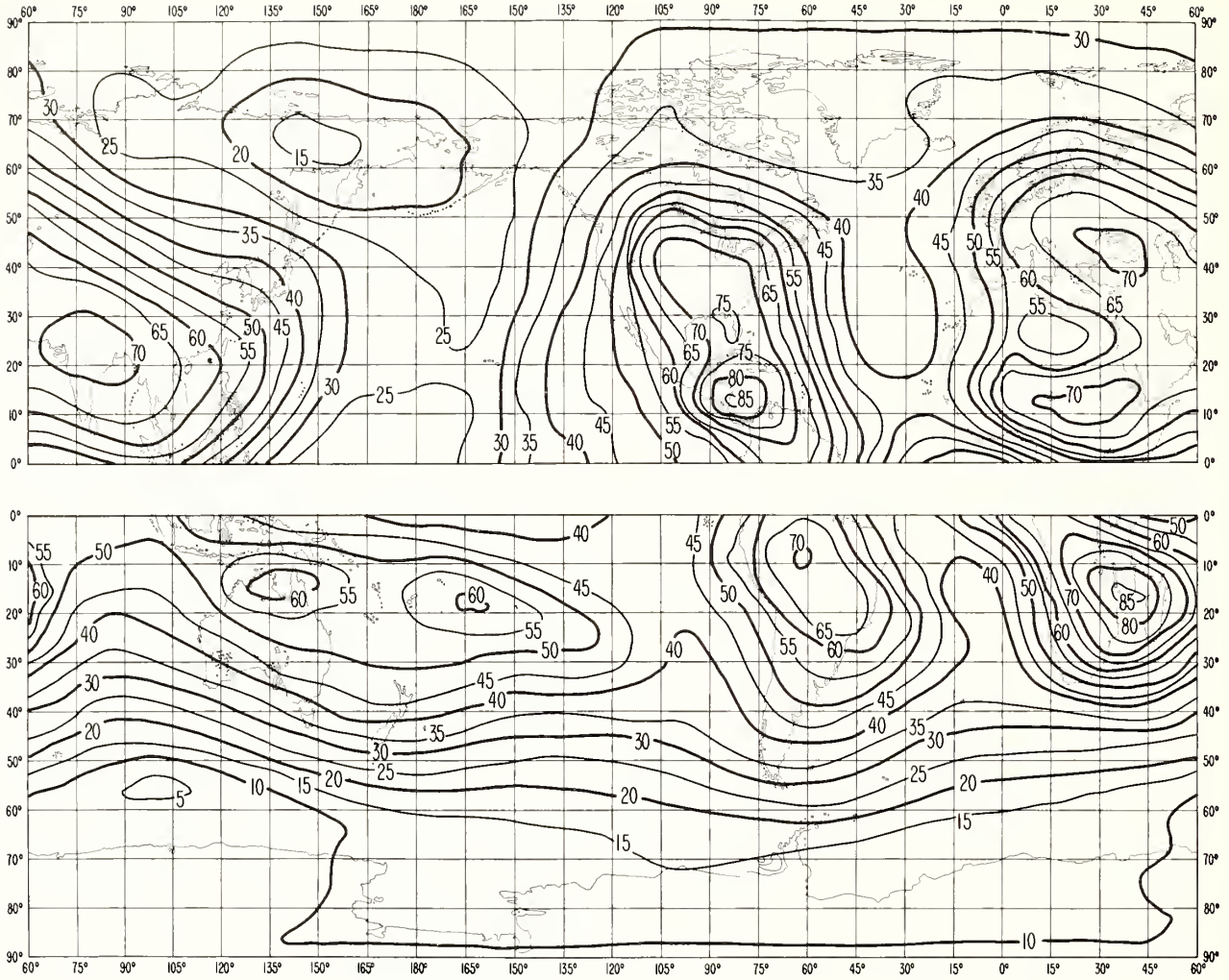

Figure 2.3-4. Typical radio noise map (contours are in decibels above a reference level).

ference levels at satellite heights for frequencies from about 100 Kc/s to 100 Mc/s, and to determine the variability of these quantities at a given point and frequency.

B. Satellite Equipment

The major item of equipment will be a receiver which sweeps from 0.1 to 100 Mc/s and measures the amplitude of the received signals continuously. The equipment characteristics are listed in Table 2.3-C. The amplitude at each frequency along with time information sufficient to locate the satellite's position, are to be stored so that they can be telemetered to earth, possibly after processing. Data handling procedures are simplified if the satellite were recovered, as it would be, in the case of a manned satellite. Besides measuring the amplitude of the signals, it is desirable to estimate the azimuth on which they are received. For satellites at heights of 200 and 400 km, noise may be received directly from circular areas on the ground with radii of 1570 and 2170 km, respectively.

With a frequency-sweep duration of 10 seconds, the satellite will move about 75 km between sweeps, whereas, with a 1-second scan, the movement is only 7.5 km. The latter is preferable because it permits more independent scans through a given signal, thus permitting better estimates of its variability.

On each 1-second scan, there will be about 10^4 channels each requiring 16 binary digits to represent the signal amplitude or, in other words, each frequency scan generates 2×10^5 bits; and in each orbit, there are approximately 5,000 scans. Thus, the total information generated per orbit amounts to

Table 2.3-C — Noise and Interference Summary of Satellite Requirements

Equipment Requirements

Frequency scanning receiver — 0.1 to 100 Mc/s.
Scan time — 1.0 sec.
Bandwidth — 0.7 Kc/s at 100 Kc/s.
24 Kc/s at 100 Mc/s.
Sensitivity — 138 dB below 1 V/m at 100 Kc/s—100 Mc/s.
Data storage — on photographic film and slow video tape (~5×10^7 bits generated per orbit).
Data retrieval — by crew.

Fixed frequency receivers 5, 10, 20, 72 and 327 Mc/s.
The 5, 10, 20 Mc/s receivers have bandwidths of 200 c/s.
The 72 Mc/s receivers have bandwidths of 10 Kc/s.
The 327 Mc/s receivers have bandwidths of 1 Mc/s.
Similar sensitivities to scanning receiver.
Data to be read out once per minute and stored for telemetry (5,000 bits per orbit).

Antennas — 3 pairs of antennas spaced and phased to give left and right cardioid patterns for frequencies between 1 Mc/s and 100 Mc/s. One earthward-looking antenna for 327 Mc/s.

Satellite Requirements

Inclination of plane of orbit — for complete coverage of earth, it should be not less than 76° from plane of equator if satellite height is 200 km, or 71° if height is 400 km.

Satellite orientation — fixed and stabilized with respect to orbit and earth.

Environmental noise level — satellite emissions and noise levels to be such that desired sensitivities listed above can be obtained. No transmissions 0.1—100 Mc/s or 322-329 Mc/s.

10^9 bits. However, since each frequency is observed once per second and the satellite moves only about 7.5 km in that time, the successive observations at each frequency will be highly correlated and some processing of the data prior to final storage will reduce the final output appreciably. An attractive method of recording the data would be to photograph continuously the face of a precision oscilloscope, whose spot is deflected in accordance with the frequency and whose brilliance is determined by the signal amplitude. With suitable "on board" calibration it is believed that the data could be recorded adequately using about 30 cm. of 35 mm. film per orbit.

In addition, a slow magnetic tape video recorder could be used to record the signals. In this way, the film record could be used to obtain numerical data without the necessity for scaling the film.

In the above discussion, it has been assumed that the data have been digitized; this may not be essential.

In the presence of interfering signals from radio transmitters, special techniques will be necessary for measuring the noise level as, for example, the method of minimum power detection.

C. Location of CW Sources and Direction Finding

As noted above, the receiver will measure the sum of the signals present at any frequency. If only a few sufficiently wide-space sources are radiating at a given frequency, then each source will give rise to a maximum signal as the satellite moves past it. Thus, it is possible to approximate the point of closest approach to a suitable ground station by determining the variation of signal level with position. This

method, of course, will not indicate whether the signal is to the left or right of the satellite, but observations on successive orbits could remove this ambiguity.

It should be noted also that at frequencies near the ionosphere critical frequency, the signals will only penetrate the ionosphere in a very narrow vertical cone. This fact could help to locate the approximate source position in certain cases.

Alternatively, the noise sources may be located by the use of suitable direction-finding antennas.

If the satellite is spinning about some fixed axis, the resulting modulation of the signals from a pair of interconnected antennas could be used to identify the direction from which a particular signal was received. In this event, the multilobe structure resulting from a spacing which exceeds one wavelength could be profitably used to increase the resolution. The exact form of direction-finding antennas must await concrete information on the characteristics of the satellites.

D. Lightning Discharge Detection

Radio noise from individual lightning strokes overlap and prevent identification of the separate discharges. Because of this fact, it is felt that relatively narrow-band observations of the background noise level in the high frequency and (very-high frequency) bands will permit observation of thunderstorms with a resolution of about 400-800 km. The swept-frequency receiver will permit such observations. In addition, however, it is planned to have several fixed-frequency receivers operating at frequencies of 5, 10, and 20 Mc/s. Also fixed-frequency observations are planned at frequencies of 72 Mc/s and at 327 Mc/s (see Table 2.3–C).

E. Environmental Noise Level

The purpose of this experiment is to measure the ambient noise and signals down to the lowest possible levels. It is essential that the contribution of the satellite system is negligible, at least for an appreciable part of the time. It is recognized that transmissions from the satellite are inevitable, so some method of identifying the times of transmission and of disabling the noise recorder is required. In addition, however, every effort should be made to avoid radiation generated within the satellite in the range of 0.1–100 Mc/s and 322-329 Mc/s as this would vitiate the observations. This protection should include noise intermodulation products and harmonics, as well as direct radiation of carrier signals. As noted above, it is expected that the minimum signal and noise levels will be about -138 dB relative to 1 volt/meter in a 1 Kc/s bandwidth.

2.3.2.5 Proposals for Future Consideration. Subsections 2.3.2.2 through 2.3.2.4 have presented potential investigations dealing with lower ionosphere studies, ionospheric mapping, and radio noise and interference surveys. Additional studies under consideration are described in the following parts of this subsection. These are still being evaluated for technical feasibility.

Ionosphere Physics

ESSA's interests in aeronomy cover the neutral and ion composition of the upper atmosphere, including trace constituents; electric fields and currents in the ionosphere; electron-density distribution, including the sheath around a satellite; and a variety of phenomena in the exosphere or magnetosphere.

A. Satellite Plasma Sheath Studies

The motion of a satellite in the atmosphere produces an electric potential on the vehicle. The attraction of this field for ambient-charged particles produces a plasma sheath around the satellite. Since various experiments (that is, charged-particle measurements) can be affected by this sheath, a detailed understanding of the sheath is important.

This plasma sheath can be measured by emitting charged particles at various energies from the satellite. The trajectories of these particles, outward and returning, are determined, in part, by the distribution of the charge near the vehicle. By measuring the time of flight with respect to energy, the density profile of the plasma sheath can be determined.

B. Charged Particles (Magnetosphere) and Very-Low Frequency Emissions

Recent theories pertaining to the generation of VLF emissions involve electromagnetic-wave/charged-particle interactions. There are a number of ways in which such interactions may take place, depending on various parameters such as particle energy, ambient magnetic field strength, pitch angle, type of particle involved, etc. The spectral characteristics of the emitted wave also rely on these parameters, which are variable over wide ranges depending on position and time. Hence, for almost any interaction mechanism proposed, there can be sub-

stituted into the theory appropriate values of the parameters to produce the observed spectral characteristics. Clearly, in order to distinguish between these mechanisms, there is a need for simultaneous measurements of these parameters in the exosphere with observations of VLF emissions.

C. Ionospheric Electric Fields

Electric fields in the ionosphere might be studied by the ejection of suitable chemicals at appropriate altitudes and latitudes. These chemicals would be ionized and rendered luminous (or otherwise detectable). Optical observations of the motions and rates of diffusion of this substance could provide a basis for determining the electric fields in the ionosphere.

D. Trace Constituents in the Upper Atmosphere

Trace constituents in the upper atmosphere contribute to the density of ionization in the ionosphere. The determination of the amounts of these elements can be helpful in quantitative explanations of the ionosphere's density. These elements could be determined by measurements of the amount of absorption in their spectra. This experiment would be performed by comparative measurements of solar radiation in and adjacent to the spectral lines by suitable instrumentation in satellites. Observations would be made of the intensity of solar radiation during the day/night transitions.

Magnetospheric Physics

E. Electron Densities

Whistlers received on the earth's surface have yielded estimates of electron densities in the magnetosphere. Such studies, by means of satellites, can lead to improvements in this technique by:

- reducing uncertainities with respect to the propagation path,
- providing a greater abundance of usable whistlers,
- reducing the corrections for ionospheric dispersion, and
- providing a means of making a better estimate of the ionospheric dispersion.

F. Magnetospheric Conjugate Point Studies

A synchronous satellite would contain instrumentation to measure energetic-charged particles, whistlers, and VLF emissions. This satellite would be placed to monitor the field line (75° W) having conjugates at the Great Whale River station in Canada and the Byrd station in Antarctica. The events obtained would be related to charged-particle phenomena (absorption, aurora, and VLF emissions) obtained at the surface stations.

G. Electron Density in the Cis-Lunar Medium

Lunar radar reflections have been used in attempts to obtain electron content in the region between earth and moon. This technique suffers from limitations which could be minimized by placing a radio transmitter on the moon. Such a transmitter would radiate two phase-locked frequencies with appropriate modulations. The phase and polarization of the signal would be measured on earth's surface. These results would then yield the electron content along with the propagation path.

Planetary Atmospheres

ESSA's interest in the earth's atmosphere, and in the ionosphere in particular, leads naturally to an interest in the atmospheres and ionospheres of the moon and planets. Studies of the planetary atmospheres may help us to better understand our own atmosphere. The following experiment has been advanced by ESSA scientists.

H. Martian Atmospheric Studies

The density, composition, and temperature of the atmosphere of Mars can be studied by measurements of its absorption of solar radiation as a function of wavelength. This experiment could be carried out best by a Martian-orbiting satellite, with measurements during the dawn and dusk transitions. From such studies, the latitudinal and temporal variations of the atmospheric parameters can be determined.

Tropospheric Physics

The physical properties of the troposphere are of interest to ESSA in order to assess the utility of the upper frequencies (e.g. millimeter, infrared and optical) for telecommunications purposes. To this end the following proposals are advanced.

J. Infrared Sensing of the Lower Atmosphere

Studies of atmospheric dynamics, thermal balance, and tropospheric-stratospheric exchange processes

are hampered seriously by the sparsity, or complete lack of, data on the infrared-active trace constituents of the lower atmosphere, particularly, water vapor, carbon dioxide, and ozone. The proposed satellite system should be able to study these constituents as a function of altitude and location.

A possible method is the measurement of the atmospheric absorption of the solar spectrum over a path tangent to the desired atmospheric level by means of spectrometers or interferometers. The motion of the satellite would provide the scan in altitude and location. Other possible techniques are discussed in Section 2.4 (meteorology).

K. Millimeter-Wave Sensing of the Lower Atmosphere

Millimeter waves, at frequencies above about 10 Gc/s, are useful for the study of tropospheric absorption and its variability. This absorption is affected by meteorological conditions such as clouds and precipitation. This proposal involves the use of satellite-borne mm-wave beacons. Signals, received by ground-based radiometers, would be utilized for studies involving telecommunications at these frequencies, for making basic physical studies relating to atomic and molecular absorption, and for atmospheric probing to determine composition versus height.

L. Chemical Releases from Manned Spacecraft

During the reentry phase of a manned spacecraft mission, ionization, caused by atmospheric heating, invokes communications breakdown. The release of a suitable chemical (C_7F_{14} or SF_6) having high electron affinity may alleviate this problem. Also, such releases may be useful in studying various ionospheric effects such as absorption and conjugate diffusion; simulation of magnetic storms, eclipses, traveling disturbances, and nuclear explosions; and the development of "anti-communications-weapons" and countermeasures. This work would be performed by ground-based observations of ionospheric effects produced by the release of various chemicals from manned spacecraft.

M. Electromagnetic Properties of the Earth's Surface

On frequencies throughout the radio spectrum, the ground wave plays an important role in telecommunications. The strength of waves propagated over the ground depends on such factors as the nature of soil, moisture content, temperature, general geological structure, and surface objects — forest, jungle, desert, grassland, and buildings.

In order to draw more accurate maps of the effective ground constants a knowledge of the surface conditions is vital. Since these conditions can vary greatly with time (that is, summer to winter), satellite observations of the surface conditions would be invaluable. Color photographs and radar scatterometer data on the roughness parameter (see section 2.4.2.4) would provide useful data for propagation calculations.

N. Information Capacity of Satellite-Ground Links

The possibility of using higher frequency bands (above 10 Gc/s), with their greater bandwidths, raises the question of limitations imposed by the atmosphere on information capacity. These distortions must be investigated before firm plans can be made to exploit the higher frequencies.

P. Optical Communications

Optical frequencies promise to be useful for space-earth and space-space communications where there are serious problems with radio frequency links.

Power considerations dictate that communication links operating in deep space need to have narrow beams, but small spacecraft antennas. This requirement is better suited to coherent light waves (laser) than to radio waves. Competent planning and engineering of optical links from space to earth require a knowledge and understanding of several propagation problems. One use of optical signals may be to overcome the reentry blackout problem.

2.3.3 Related NASA Programs

2.3.3.1 Aeronomy. In recent years the investigation of the earth's upper atmosphere has provided rough models of the principle characteristics and properties to several thousand kilometers in altitude. The physical structure (i.e., pressure, density, and temperature) and the chemical composition of neutral and ionic components have been determined in a general way, but variations in the upper atmosphere with time and geographical position remain quantitatively unknown.

Structure measurements from balloon altitudes to about 250 km have been made by a number of techniques, including grenades, falling spheres, mass spectrometers, chemical releases, and observations of

airglow and aurora. Above 250 km, satellite drag observations have given information on atmospheric density and its temporal variation. More recently, *in situ* measurements have been made by Explorer series and sounding rockets.

NASA is conducting a research effort using rockets and satellites to obtain quantitative data over sufficiently long time intervals and with adequate geographic coverage to study aeronomic problems at all altitudes in the high atmosphere. The categories of rockets used will range from smaller Arcas and HASP rockets to the larger Argo D-4 (Javelin).

Satellite payloads will be of two general types, the smaller single purpose satellites and the observatory class satellites which can carry as many as 25 experiments with emphasis on correlated observations. The geophysical observatories, for example, are designed to study the interrelationships of particle activity with auroral and airglow phenomena, the magnitude and fluctuations of the geomagnetic field, the neutral and ionic composition of the upper atmosphere, and the electromagnetic energy sources contributing to ionization and atmospheric heating.

The early requirements of planetary (Venus, Mars) exploration for Aeronomy-related studies will be met by the Mariner and Voyager spacecraft, including the fly-by orbiters and landing probes. Requirements and capabilities are being formulated for investigation of other planets.

2.3.3.2 Radio Physics. The NASA program in this area is directed toward two broad goals: a detailed knowledge of the interaction of electromagnetic waves with ionization, including their propagation characteristics, generation mechanisms and effects on the distribution of energetic particles; and an understanding of the origin, distribution, and temporal variation of ionization in space. Since the

Orbiting Geophysical Observatories (OGO) E, F, (1968-1969)

Instrumentation	Application
Particle counters and analyzers	Neutral particle, electron, and ion densities, composition, temperature, and energy spectrum
Photometers, optical and UV	Aurora and airglow
Magnetometers	Magnetic field and fluctuations
VLF antenna and receiver	Electrostatic and electromagnetic phenomena
Electrometers	Magnetospheric electric field

European Space Research Organization (ESRO) I (1967)

Instrumentation	Application
Particle counters and analyzers	Electron and ion density temperature, composition
Photometer	Aurora

International Satellites for Ionospheric Studies (ISIS)-A (1968) and (ISIS)-B (1970)

Instrumentation	Application
Ionosonde	Electron density profile ionospheric irregularities
VLF receiver	VLF emissions
Particle counters and analyzers	Particle composition, density, and temperature
Radio beacon transmitter	Electron content
Photometer	Auroral and airglow emission

earth's ionosphere is produced by interactions of solar radiation and energetic particles with the neutral atmosphere, the studies of solar physics and the neutral atmosphere are closely associated with those of the ionosphere itself.

Ground station based propagation techniques (ionosondes and incoherent scatter radar) are supplemented by propagation experiments in which radio signals are propagated from a rocket or satellite to ground and by direct sampling techniques using space vehicles.

Spacecraft and sensors relating to the NASA program in aeronomy and radio physics include the following:

SAN MARCO

Instrumentation	Application
Strain gage balance	Atmospheric parameters
Radio beacon transmitter	Ionospheric electron content

Applications Technology Satellites (ATS)-C, D, (1967-1968)

Instrumentation	Application
Beacon radio transmitters	Total ionospheric electron content
Particle counters	Energetic particle measurements
Magnetometers	Magnetic field strength
VHF and microwave transponder	Communications
Electrometer	Magnetospheric electric field

OWL EXPLORERS (1968)

Instrumentation	Application
Photometers	Auroral and airglow emissions
Particle counters	Trapped particles

2.4 METEOROLOGY

In the field of meteorology, satellite technology is perhaps more advanced than in some of the other geophysical areas. As a consequence, many of our proposals require only refinements of systems which are either in existence or under development. For example, high-resolution multiband imaging, a common requirement for many meteorological problems, represents essentially an improvement in existing scanning systems. There are, however, important new concepts which deserve vigorous development. In addition, manned space technology, with its large, versatile payloads, is now opening the door to experiments whose complexity, weight, or power requirements exceed present unmanned satellite technology.

2.4.1 Description of Scientific Field Considered

Meteorology is concerned with the physics, chemistry and dynamics of the atmosphere and its effects on the oceans, the earth's surface and life in general. It implies the physical understanding of the atmosphere and strives toward accurate prediction and eventual control of the atmospheric environment.

In this report meteorology is viewed primarily from the standpoint of weather prediction and its supporting research programs. Bounded by the ocean and solid earth below and by the ionosphere above, the "meteorological atmosphere" considered here extends to about 50 miles above the earth's surface. This somewhat arbitrary definition does not ignore the important interfaces with oceanography, and aeronomy. Hydrology, because of its special role, is treated separately in the next section.

In addition to short- and long-term weather forecasting, the responsibilities of ESSA for special services have been taken into account such as hurricane and tornado warnings, marine and aviation weather, and agricultural and forest services. The fields of weather modification, general circulation, air pollution, atmospheric electricity, and other research areas which support operational programs, are also discussed.

2.4.2 Proposals and Related Requirements

2.4.2.1 Scope. Table 2.4–A gives a survey of the meteorological proposals which have survived a major screening by the Panel on Meteorology. Even this reduced list gives an impression of the wide range of meteorological problems awaiting investigation by a global-monitoring system. The emphasis in this section is on possible extensions of existing programs and on interesting new ideas to solve some of the global problems in meteorology. This emphasis in no way distracts from the urgent need to improve and fully exploit present systems. Refinements in the quality of cloud photography, of infrared sensors and of ground based readout and display facilities are among the primary requirements of the meteorological world community.

Those proposals marked in Table 2.4-A with asterisks have been given priority on the basis of the selection criteria described in subsection 2.1. Not every subject contained in this table is discussed in the report, although documentation covering problem description, improvements desired, data and resolution required, etc., is available in each case.

Selected proposals in the following areas are described in detail:

(1) The vertical structure of the atmosphere on a global scale (density, temperature, water vapor, wind).
(2) Ground and Sea surface temperatures.
(3) Surface roughness
(4) Ice and snow cover.
(5) Weather modification.
(6) Tropical flow and Convection Fields.
(7) Global Cloud Census.
(8) Atmospheric Electricity.

Priority is given to those global data requirements which are vital to the improvement and extension of numerical weather prediction.

2.4.2.2 The Vertical Structure of the Atmosphere on a Global Scale. It is generally accepted that for weather predictions in excess of a few days, the earth's atmosphere must be treated as a single dynamic system. At present, numerical forecasts are prepared routinely for periods of 3 to 4 days, and for areas covering about one-third of the earth. To extend forecasts to longer periods or to larger areas requires knowledge of the initial state of the atmosphere on a global or at least hemispheric scale. Otherwise, unknown disturbances will migrate into the prediction areas and contaminate the forecast (ICIMP Report, 1966). The required horizontal resolution is determined by the dimensions of macro-scale disturbances. A grid spacing of about 500 km is considered adequate at this time.

It has been estimated that less than 20 percent of the earth's surface is adequately covered by upper air observing stations. Unless this situation is corrected, it is hopeless to expect a substantial advance-

Table 2.4-A—List of Proposals for Meteorology

Proposal Number	Descriptions	Special Orbits
1	Vertical structure of atmosphere	Polar
*(a)#	Density/temp./pressure	
*(b)#	Winds (clear, clouds, stratospheric, mesospheric)	
*(c)#	Water vapor	
(d)	Ozone	
2	Surface conditions	Polar
*(a)#	Temperature conditions	
(b)#	Winds (oceans, from sea state)	
*(c)	Surface roughness	
*(d)#	Ice and snow cover	
(e)	Soil moisture	
(f)	Frozen ground	
3	Special phenomena	
(a)#	Jet stream/clear air turbulence	
(b)	Forest fires	
(c)	Squall lines/tornadoes	
(d)	Hurricanes (cloud structure, temp. field, pressure, radiation)	
(e)#	Mountain Waves	
4	Cooperation with:	
*(a)	Weather modification experiments	Synchronous
(b)	Weather satellite operations	Polar, synchronous
5	Clouds	
(a)#	Interpretation (cirrus, meso forms, *tropical flow fields, identification)	Polar or high inclination, synchronous
*(b)#	Global census and cloud climatology (types, cover)	Polar
(c)#	Organization and development	Synchronous
(d)	Ice versus water clouds	
(e)	Cloud top altitude	
6	Atmospheric electricity	Polar or high inclination
*(a)	Lightning (horizontal length, wide-band sferics, upward strokes)	
*(b)	Electric fields at flight level	
7	Radiation	
(a)#	Solar constant	
(b)#	Albedo (angular variations)	
8	Precipitation	Polar
(a)#	Present	
(b)	Past	
(c)	Intensity	
9	Atmospheric constituents and aerosols	Polar or high inclination
(a)	CO_2, CH_4, SO_2, CO, NO_x	
(b)	Turbidity, pollution	
(c)	Aerosol layers	
(d)	Pluming	
10#	Interrogation and relay of surface and airborne observations	Synchronous

#Requirements of major importance *Proposals selected for detailed discussion

ment in weather forecasting (National Academy of Sciences, 1966 c).

Most prediction models require knowledge of the initial flow and mass distribution of the atmosphere, and use primarily the height field of standard pressure surfaces. The customary way to obtain the mass distribution of the atmosphere is to measure, *in situ,* by radiosonde balloons, temperature as a function of pressure and to integrate upward from the surface to obtain pressure as a function of height. From a space platform, other ways are conceivable. Because the hydrostatic equation relates the vertical pressure gradient directly to density, the latter quantity is a natural choice for the basic observation. After an accurate data pair of density and absolute height has been obtained, it is a matter of integrating downwards to derive the desired pressure-height field. Theoretically, even the surface pressure can be obtained in this way. A concept of continuous remote sounding to measure density and its horizontal gradients from space is described under A below. Another possibility to determine the global mass distribution of the atmosphere is the the measurement of vertical temperature profiles from space. The infrared spectrometer designed to obtain this information is described under B, below. (Also discussed in this section is an infrared method to determine profiles of water vapor concentration.)

The remaining alternative is to measure the flow field directly; this is being done routinely by rawinsondes and pibals over many parts of the world. This type of data is especially important

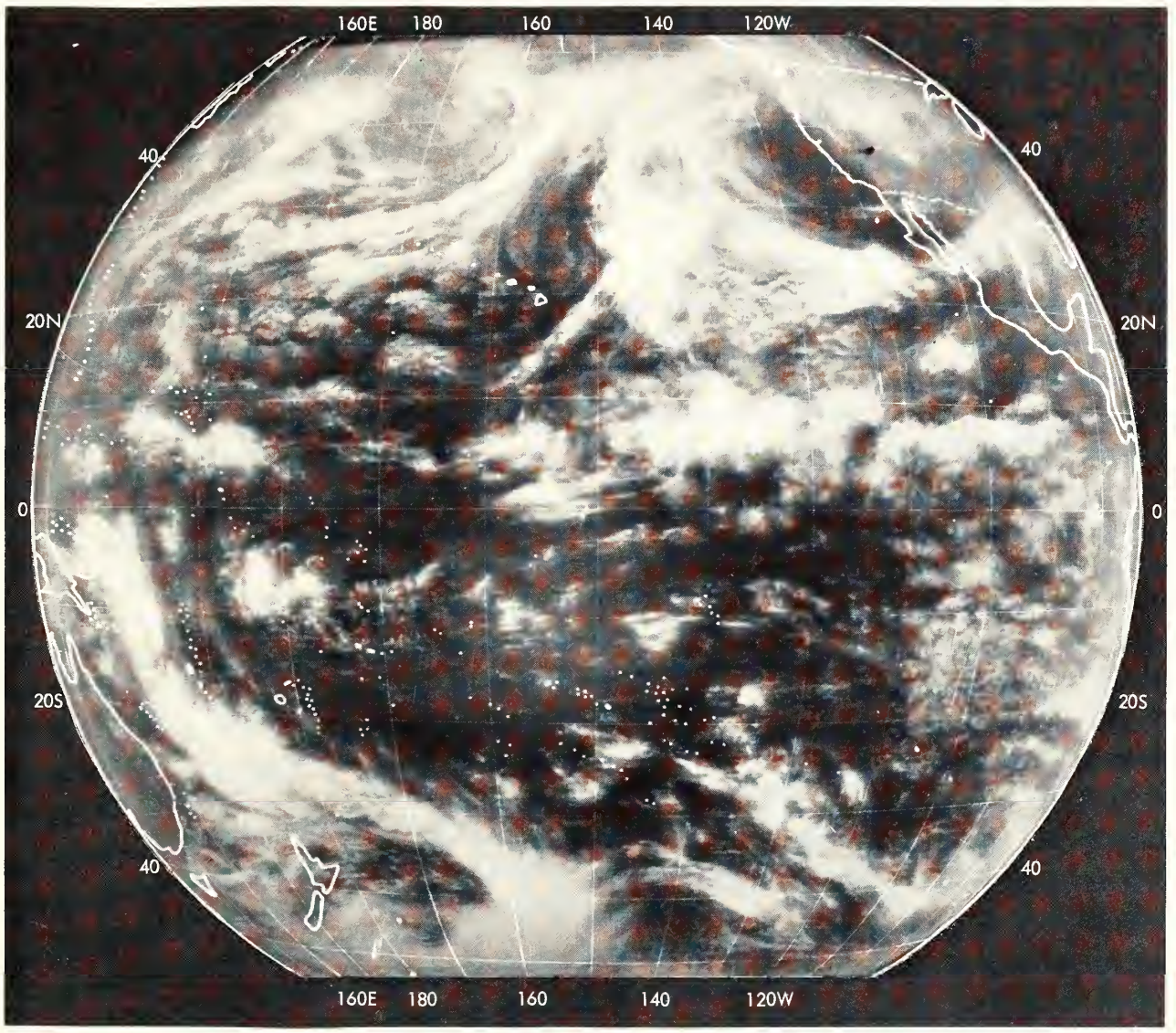

Figure 2.4-1. The cloud field over the Pacific Ocean between Australia and America as viewed by the ATS-1 satellite from synchronous orbit on January 7, 1967 at 2213Z.

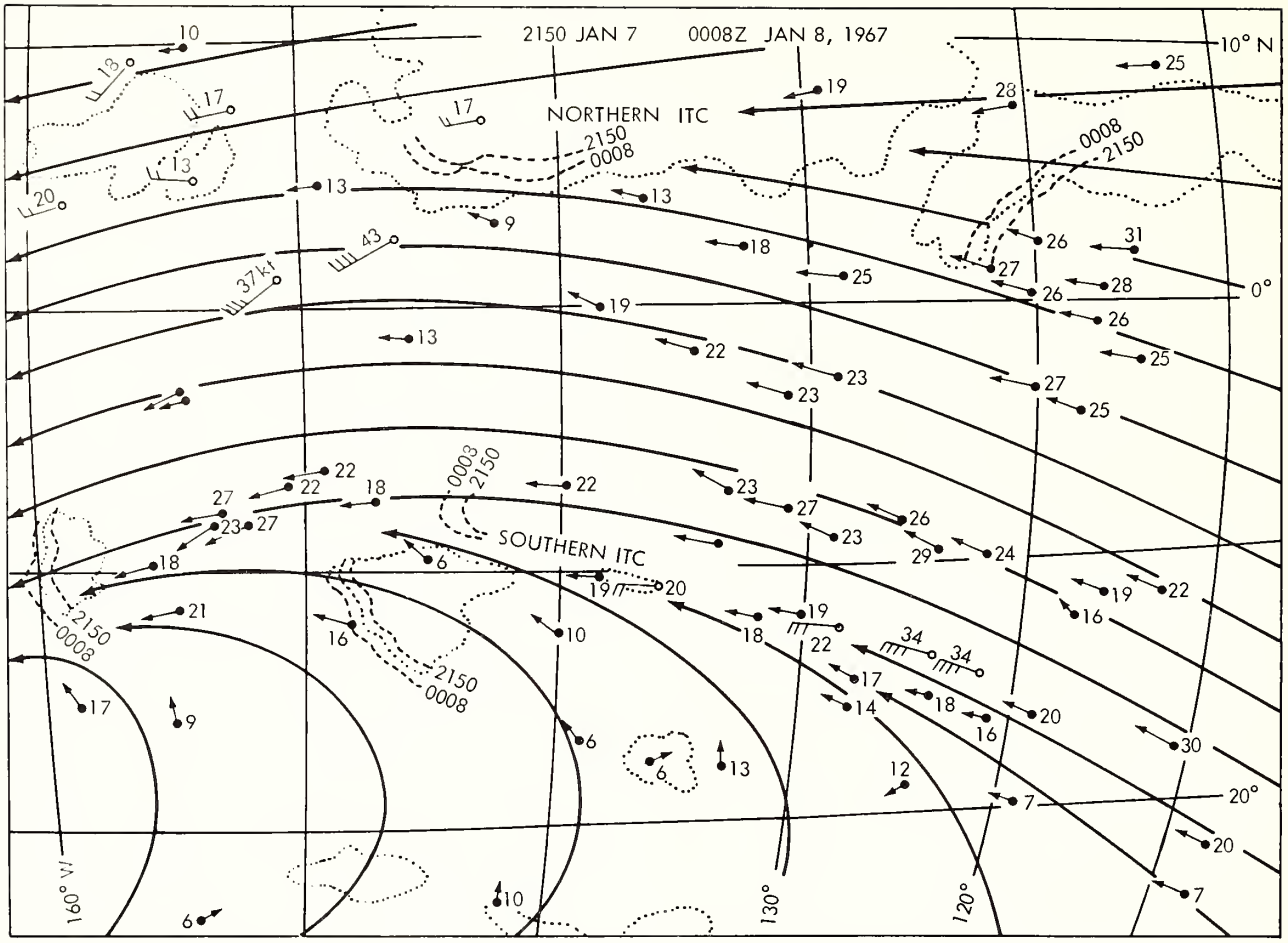

Figure 2.4-2. Winds in the lower troposphere (short arrow) and the upper troposphere (wind barbs) over the Central Pacific as derived from Figure 2.4-1 and successive frames on January 7/8, 1967. Streamlines (with arrowheads) are also shown. The dotted lines delineate cloud fields, the dashed lines the displacement of their edges between 2150Z, January 7 and 0008Z, January 8, 1967. Numbers on short arrows give wind speed in knots. ITC = Inter Tropical Convergence Zone. Note the strong vertical wind shear in the Southern ITC.

near the equator where the geostrophic assumption connecting mass and flow field breaks down. It is however, just in the tropical zones where wind data are conspicuously absent.

Here, a significant advance has recently been made by the earth synchronous Advanced Technology Satellite, ATS-1. Stationed over the mid-Pacific its onboard spin scan system (Suomi Camera) is able to observe the cloud field over the Pacific every 23 minutes. By evaluating consecutive frames Fujita and Suomi* have been able to deduce, after proper gridding, the wind-field in the lower and upper troposphere over the Pacific from the horizontal displacement of low and high clouds.

The example given in Figure 2.4-1 shows the Pacific Ocean between Australia and America as seen from synchronous orbit on January 7, 1967. The following figures give the evaluation, on the same day, of two sections within this area, Figure 2.4-2 near the center, Figure 2.4-3 near the lower left. The impressive wind information obtained by this method is estimated to have a 5 knot accuracy if, as in this case, 6 consecutive frames covering about 2 hours are used. (Smaller intervals are considered insufficient, longer intervals conflict with the lifetime of small cloud systems.)

The low level wind and streamline field depicted in Figures 2.4-2 and 2.4-3, applies to approximately 1 km height, the upper field to roughly 10 km. Features such as vertical shear (Figures 2.4-2; Southern Inter-Tropical Convergence Zone) and jetstream (Figure 2.4-3) can clearly be seen.

*Report to be published shortly.

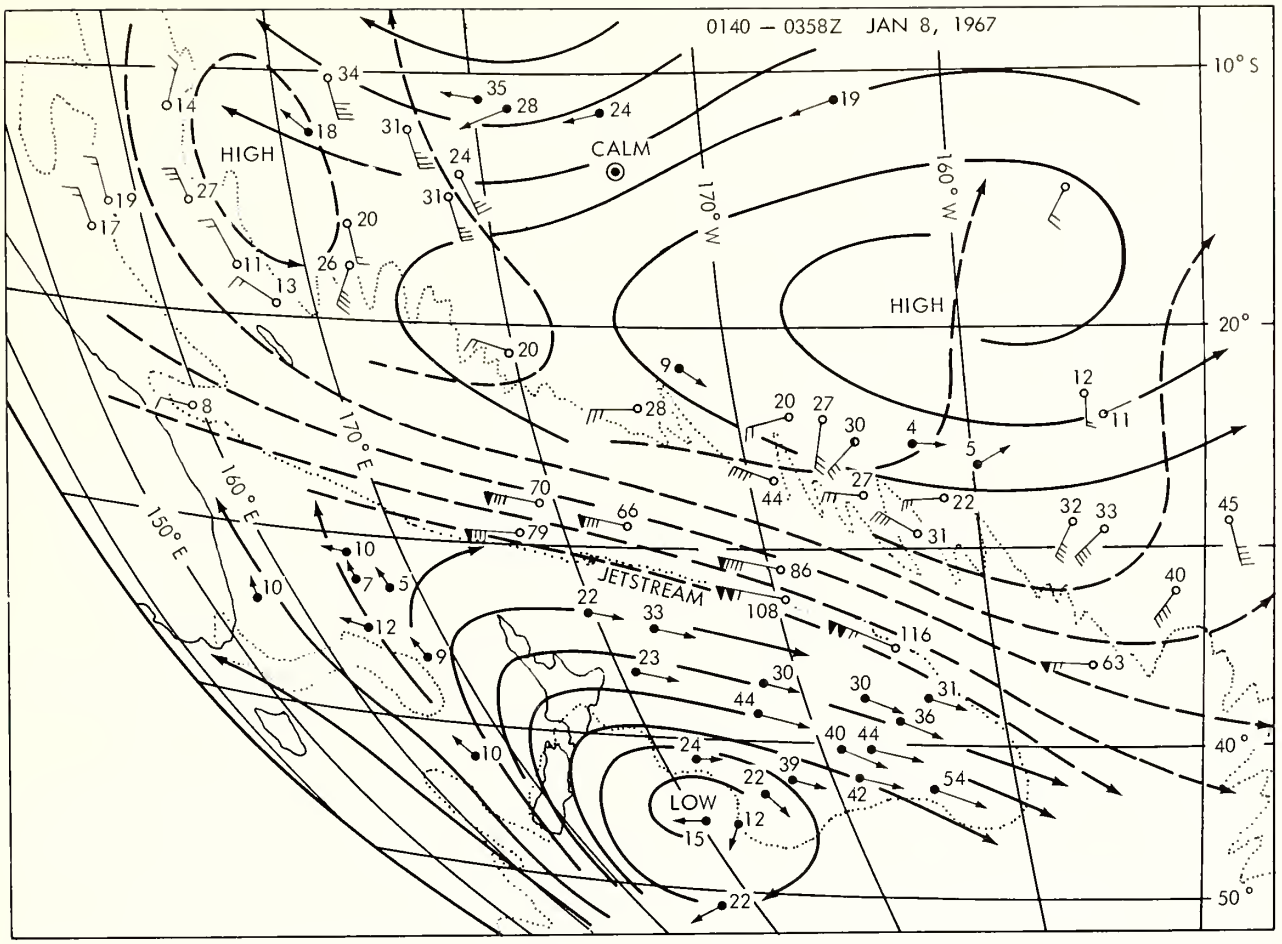

Figure 2.4-3. Winds in the lower and upper troposphere over the Southwest Pacific as derived from Figure 2.4-1 and 6 consecutive frames on January 7/8, 1967. Long dashed lines with arrowheads are approximate streamlines in the upper troposphere. For other symbols, see Figure 2.4-2. Note that the upper air flow continuous from equatorial regions through a jetstream to middle and high southern latitudes.

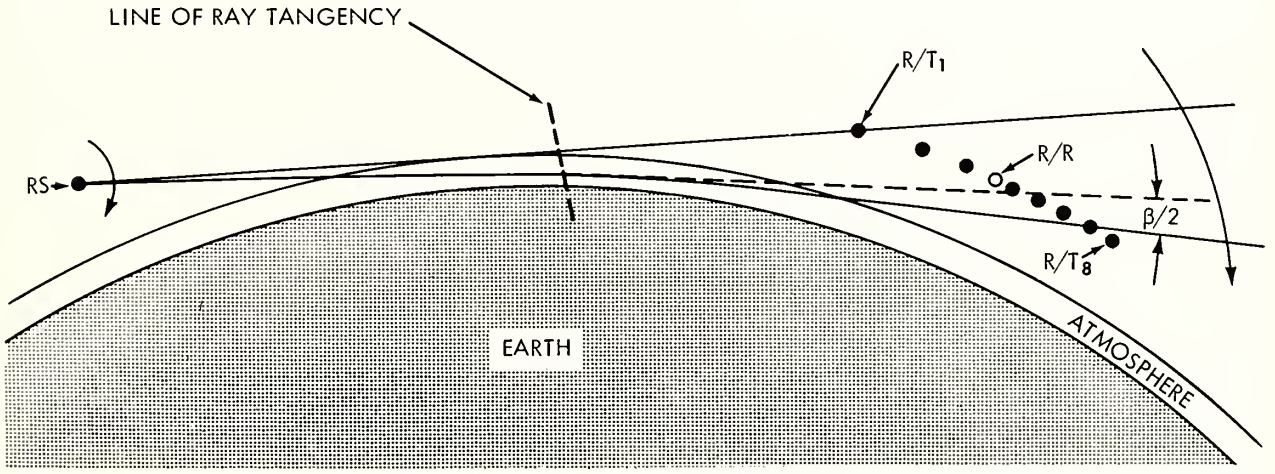

Figure 2.4-4. Relative positions of radiating source (RS), receiver/transmitter (R/T), and receiver/recorder (R/R) satellites as they circle the earth along the same orbital path to measure atmospheric density profiles by radio occultation method. β = total bending angle (see Fig. 2.4-5).

A more sophisticated system for remote sensing of vertical wind profiles in clear air is discussed below under C.

For input into the numerical prediction models, two possibilities exist: (1) vertical soundings at each grid point, or (2) an average vertical sounding for each unit area. The conventional method of using radiosondes corresponds to the first possibility, the density sounding technique described below to the second. The equivalence of the two methods should be verified.

The potential of a global system of measuring density from space for programs such as the World Weather Watch and the Global Atmospheric Research Project (GARP).

A. Global Density Sounding System (Radio Occultation Technique)

1. General Concept

The system proposed by Werbowetzki, 1966, visualizes a satellite sending radio signals to a number of co-orbital slave satellites spaced such that a spinning radio beam traverses different parts of the atmosphere (Fig. 2.4-4). The resulting refraction of the beam is a function of the atmospheric density distribution and can be measured by several techniques. The radiating master satellite transmitting the beam tangentially through the atmosphere would be similar to the current ESSA operational meteorological satellites; which are essentially spinning wheels with the spin axis perpendicular to the orbital plane (see Fig. 1.3-1). The peculiarity of the technique employed is that the measurements obtained are practically independent of the travel time of the signal from the radiating satellite to each receiver. During each spin of the master satellite, the fan shaped vertically thin beam is turned on just prior to the time it can sweep past the nearest receiver satellite. Then, sequentially, each trailing receiver satellite detects the downward sweeping beam. The times of detection are recorded for each spin and provide the raw data from which relative density values are obtained.

It is known that the spin rate of the beam greatly affects the differences in time of beam detection at the individual receiver satellites. Therefore, the spin rate should be analytically selected to minimize or negate the effect of beam pattern fluctuations. It can be chosen to either increase or decrease the time intervals between receiving satellites. For example, a 5 second spin period would cause a total time differential of approximately 16 milliseconds between the first and last receiver satellite. A careful study should determine whether a very fast, slow or moderate spin rate would be best suited.

Measuring density rather than temperature from space has the peculiarity that the technique is more sensitive at lower levels where density is high and the index of refraction changes more rapidly with height. In contrast, temperature soundings from space are more suitable at higher atmospheric levels, and run into difficulties close to the ground. A combination of both techniques appears very attractive. It should be kept in mind, however, that the rate of change with height in the atmosphere is less for temperature than for density; therefore, accurate height determination is more critical for density than for temperature-measuring techniques.

It is interesting to speculate to what degree a global density measuring system would be useful by itself and how it would be affected by:

(a) a constant but small error in the absolute value of density,

(b) insufficient knowledge of ground pressure, and

(c) lack of wind information.

Computer experiments exploring this group of questions are underway; preliminary investigations justify some optimism if the forecast period exceeds a few days. More specifically, it appears that a geostrophic approximation would adjust itself in a matter of hours to the proper divergent wind field without seriously affecting the mass field. Other forms of initial adjustment of wind and mass fields presently under development by Mintz and others are promising. This may eliminate the need for observational determination of the horizontal wind velocity, at least in latitudes outside the equatorial belt.

2. System description

A possible system configuration consists of the three types of spacecraft: the first, a radiating source (RS); the second, a receiver/transmitter (R/T); and the third, a receiver/recorder (R/R), Figure 2.4-4. The radiating satellite transmits a rotating microwave beam tangentially through layers of the earth's atmosphere toward the sequential group of R/T satellites which follow each other in the same orbital path at prescribed intervals to provide optimum altitude coverage. As each R/T satellite detects the transmitted signal, it relays this event to the R/R satellite.

The R/R satellite contains an accurate clock from

which the time is sampled and recorded. It relays these recordings to ground readout stations orbit-by-orbit. The ground station then sends the information to a central processing facility for further analysis and dissemination.

The system has the following characteristics:

(a) The RS satellite provides a beam of appropriate energy, frequency (over 3,000 Mc/sec) and beam width (wide, flat beam).

(b) The first of the R/T satellites is located so that only an unrefracted beam is detected for each revolution of the radiating source. This provides determination of an accurate spin period of the beam. If the power transmitted and received for each scan is recorded and known, beam pattern fluctuations can be compensated for, providing accurate relative times of arrival of the beam at each R/T satellite. Additionally, each R/T satellite which receives a signal from the radiating source can also relay data concerning signal strength received, which provides information on the water vapor content of the atmosphere.

(c) The R/R satellite is the collector of all data for playback to the ground.

(d) The orbital parameters of all satellites are obtained via tracking stations and are utilized in the analysis and computation of results.

The time of arrival of the signal at the R/T satellite is a function of the refractive index change along the path as determined by the density of the atmosphere. Although the total bending angle is an integrated effect, maximum refraction is concentrated at the tangential (lowest altitude) point of beam path (Fig. 2.4-5) so that the change in time of arrival is a measure of the atmospheric density at the height of the tangential point. With the proper number and spacing of the R/T satellites, density can be measured at several atmospheric levels, giving an approximate vertical density sounding.

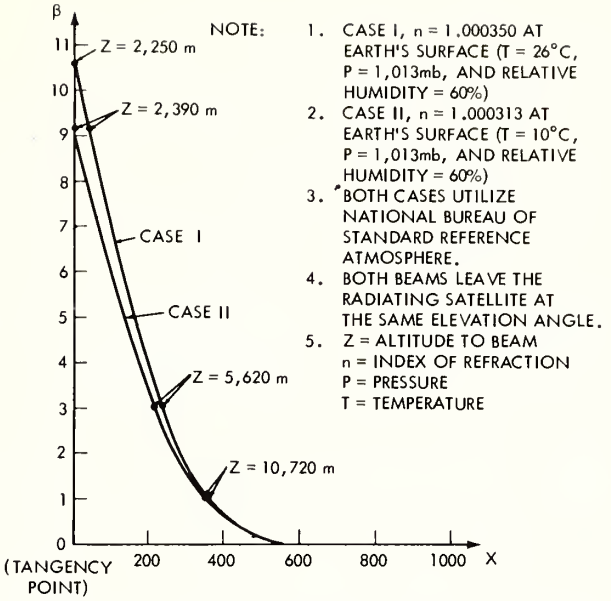

Figure 2.4-5. Global density measuring experiment. Total bending angle of beam β (milliradians) versus horizontal distance X (kilometers) from tangency point for two reference atmospheres.

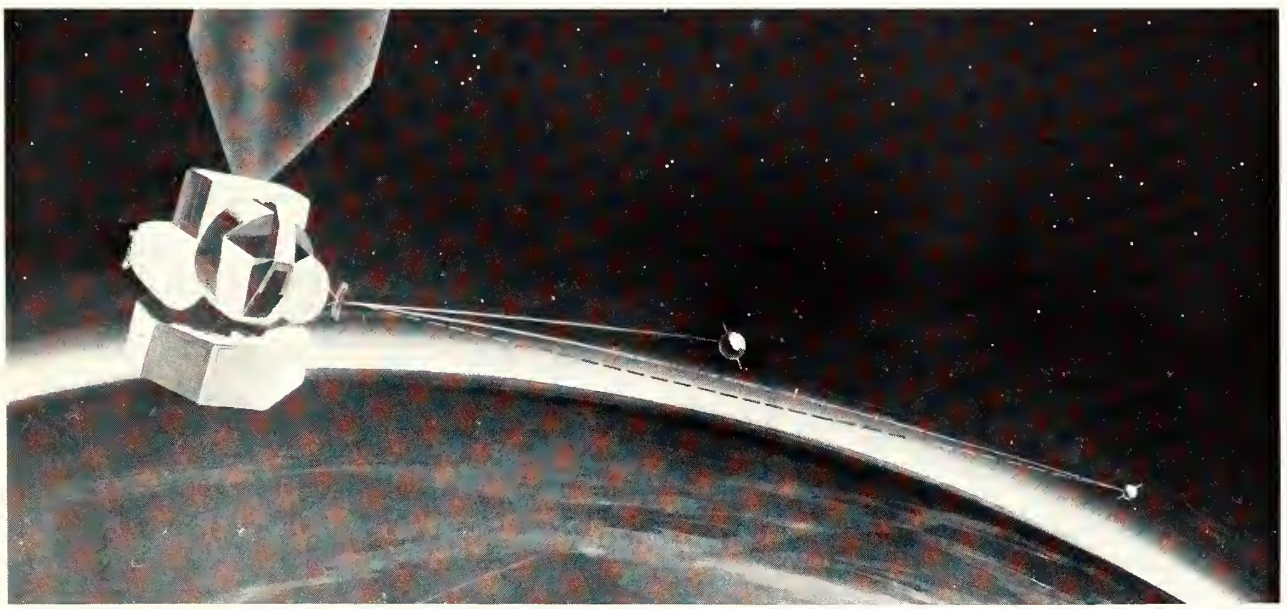

Figure 2.4-6. An R&D experiment utilizing an orbiting laboratory and slaves to test an atmospheric density measuring system.

To indicate where and how much bending has occurred as the beam traverses the atmosphere, a computer simulation was performed utilizing two different atmospheres (see Fig. 2.4-5).

In each case, the path of the beam started from the radiating source at a local elevation angle of -0.245 radians. For the assumed orbital height (200 km) this angle is best suited for probing the lower levels of the troposphere, between 2 and 2.5 kilometers. As one looks at points along each path, significant differences in total bending angle over the same local point begin to appear at an altitude of approximately 10 kilometers. Also, as one traces toward each atmospheres' tangency point where the local elevation angle = 0°, the separation in altitude of both beams becomes more and more pronounced. It is at the tangency point that the greatest contribution to the bending angle is made.

As the satellite family proceeds along its orbit, it continuously measures the horizontal variation of the density profile; that is, as the satellites move in orbit between scans, increments of "new" atmosphere take effect and horizontal gradients (different time recordings) are detected. The differences between sequential scans can be plotted as an envelope of changes in integrated refractive index for each R/T satellite. The envelope is produced by connecting the peaks of the sharply pointed bell shaped curves. This provides an average density value (at the altitude of the tangency point) over a path length of approximately 300 miles (150 miles on each side of tangency point).

The horizontal separation of peak values is a function of spin period and orbital period of the satellite family. For a 1 second spin period and a 90 minute orbital period a measurement is made every 4 nautical miles. Absolute density values can be obtained from the horizontal gradients by passing over a conventional station using in situ sounding techniques.

Typical spacing of satellites, assuming an altitude of 300 km, would be:

(a) RS to nearest R/T satellite = 3000 km, and

(b) nearest R/T to farthest R/T satellite =300 km.

The deployment of the satellites may be performed best from a manned space platform. After proper checkout, a satellite is released and the platform pulled away, allowing the satellite to drift free. The space platform is then repositioned for the next satellite. Figure 2.4-6 illustrates an R&D test of this system. A careful study is necessary to determine differential drifting and lifetime of the satellite system.

To correlate data received from this satellite sounding system, it would be advantageous to operate a polar-sounding station where local vertical profiles of the atmosphere could be obtained from ground-released devices. Calibration of the satellite system might not be required very often, but a calibration could be obtained for any orbit utilizing a vertical-sounding station located near either pole.

In comparison to an "optical occultation system" (Fischbach, 1965), the following benefits might also be obtained by this radio occultation technique:

(a) A known radiating source would always be available.

(b) Atmospheric refraction could be measured on both the lighted and dark sides of the earth.

(c) Clouds could be penetrated.

(d) Scans could cover levels below the 500-millibar level.

(e) Information could be obtained concerning the effect of atmospheric conditions on microwave propagation.

(f) Atmospheric ducts could be located by an irregular sequence of time recordings indicating temporary trapping of the beam as it spins downward.

(g) Global contours of refractive data by altitude would become available on a daily basis.

3. Phase Shift Measurement Technique

The above-described method is based on obtaining time measurements as a function of atmospheric

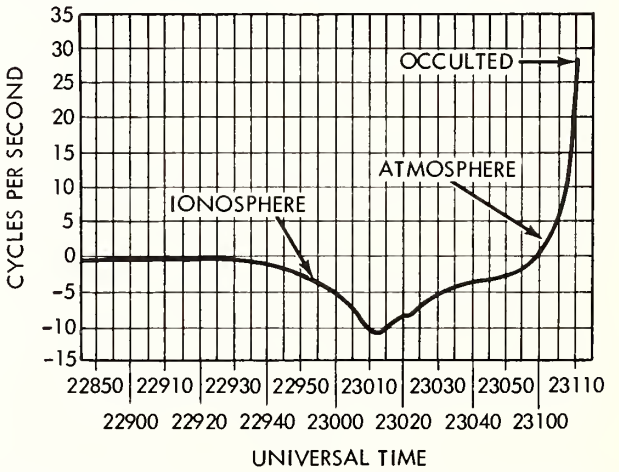

Figure 2.4-7. Mariner – IV radio occultation experiment. Phase change of S-Band signal (2.1 Gc/s) vs. time due to Martian atmosphere. (Kliore, et. al. 1965).

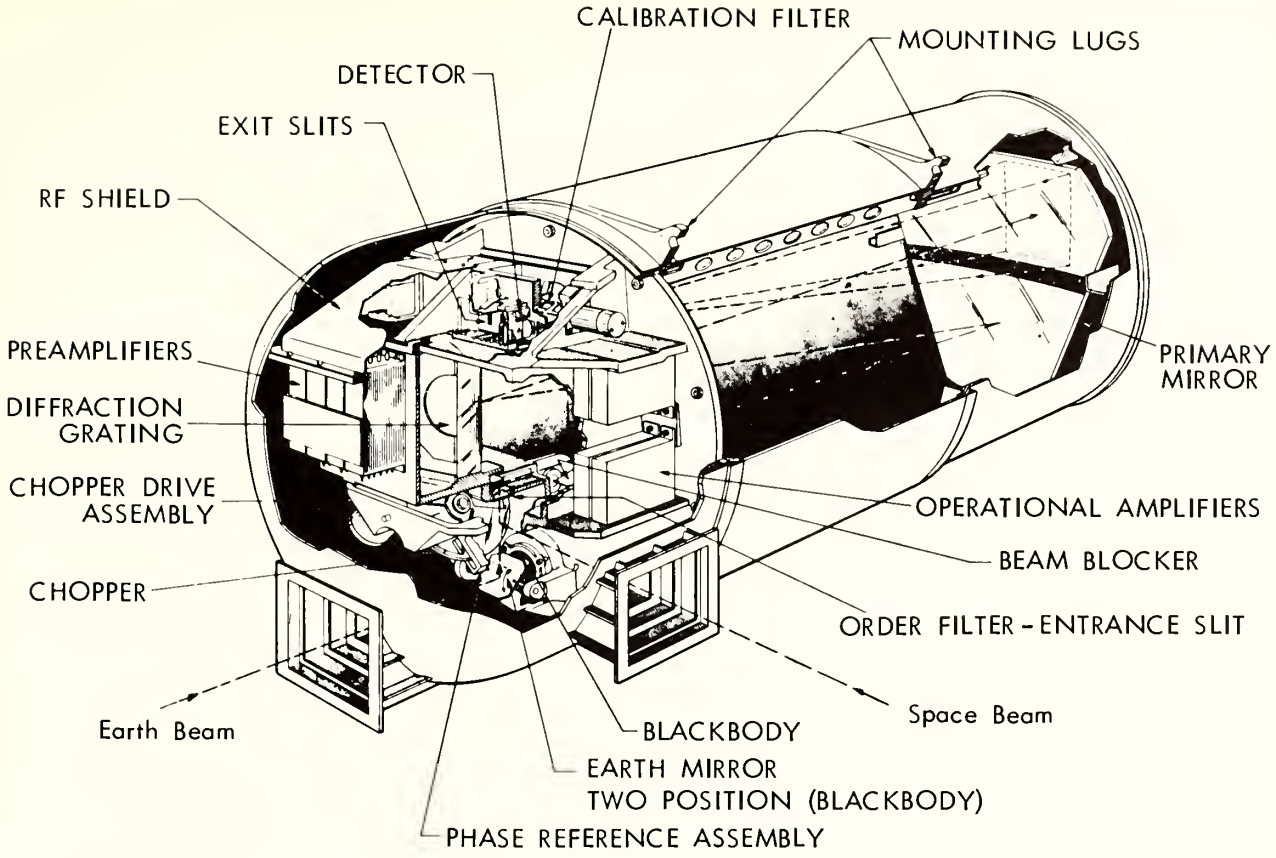

Figure 2.4-8. Satellite infrared spectrometer (SIRS) for the measurement of atmospheric temperature profiles, developed by ESSA for flight on Nimbus B.

density variations. Another interesting possibility for obtaining density data involves measuring phase variations of a radio wave as it passes tangentially through a planets atmosphere. This was the method used in the Mariner IV experiment for measuring the Mar's atmosphere (see Fig. 2.4-7).

As shown by a University of Stanford design study (SPINMAP, 1966) a radio beam coming from outside the atmosphere, grazing the earth at sea level and emerging on the other side, undergoes a "virtual path length change" of approximately 1200 meters (neglecting ionospheric effects) which takes into account the increase in distance (due to bending) and the decrease in propagation speed of the signal. Both are functions of the atmospheric density. As the interrogating signal from the source satellite (for example, an Apollo spacecraft) and the returning signal from the transponder satellite, are equally affected by the atmosphere, the total apparent change in path length grazing the earth at sea level would be approximately 2,400 meters or 16,000 wavelengths at 2 Gc/s.

Many of the perturbing effects previously mentioned reduce the accuracy of the system to a fraction of the theoretical resolution. It is expected, that changes of 1 part in 1,000 corresponding to relative ground pressure changes of 1 millibar can be detected. It appears that uncertainties introduced by drift between the satellites, orbital eccentricities and asymmetry of the earth's gravitational field can be removed by statistical methods. Oscillator instability will cause minor errors. As in all refraction methods, the presence of water vapor will introduce uncertainities which have to be resolved by independent measurements of water vapor concentration (see following section B).

B. Global Temperature and Water Vapor Sounding Systems

Projects to measure vertical temperature profiles of the atmosphere from satellites by remote sounding have been pursued actively for a number of years. The principle, first suggested by Kaplan in

1959, is based on the measurement of atmospheric radiance in a number of narrow spectral intervals within the infrared absorption band of a uniformly mixed atmospheric constituent such as carbon dioxide. The actual profile is then deduced by an inversion of the integral transform (Wark and Fleming, 1966).

There are different types of spectrometers which can be used for this purpose, such as narrow band pass filter radiometers, interferometers, filter wedge radiometers, etc. . . . Developed under NASA's sponsorship they are to be tested in the near future on manned and unmanned spacecraft (see Section 2.4.2.11).

One of these spectrometers developed by ESSA has been flown successfully on balloons. It is expected to measure temperature profiles directly beneath the satellite down to the cloud top level or, in clear areas, to the ground (Hilleary, et al, 1966). The spectrometer, shown in Figure 2.4-8, is now being prepared under NASA sponsorship for flight on Nimbus B.

An advanced version for Nimbus D is being designed to also measure several radiances in the rotational water vapor band (18-50 microns). Using the temperature information obtained independently from the carbon dioxide band it is then possible to determine profiles of water vapor concentration down to the cloud top level or, in cloud free areas, to the ground. The instrument is arranged to operate at various nadir angles so that a geographic grid distribution of temperature and water vapor profiles can be obtained. In the tropical areas the water vapor profiles may be more useful than the temperature profiles, especially in the lower layers, because the horizontal variations in temperature over the tropical oceans are generally quite small.

Finally it is possible to derive the horizontal temperature distribution of the stratosphere (20 to 25 km) on a global scale from measurements near the center of the 15μ carbon dioxide absorption band. (Nordberg et al. 1966). Since a high correlation exists between these patterns and the 30 mb temperature field (Warnecke, 1966) the coming supersonic transport (SST) may benefit highly from global operational maps of this type.

C. Wind Sounding Systems

As has been pointed out in the beginning of this section it is desirable to know the global distribution of atmospheric flow as an initial condition for numerical weather prediction. Even if it were possible in middle and high latitudes to do without wind information by applying the geostrophic approximation of the mass field (see A.1 above), the tropical zones would still require the horizontal velocity as the primary observational parameter. Conventional methods to determine upper winds require "in situ" measurement by balloons rising or drifting in the atmospheric flow. To achieve this on a global scale with sufficient horizontal and vertical resolution requires a very large system indeed. The "World Weather Watch" is considering, as one alternative, a Global Horizontal Sounding Technique ("GHOST") using balloons which float at constant density surfaces (ICIMP Report, 1966) and are interrogated by synchronous satellites.

For later phases of the World Weather Watch a remote-wind-sounding system would be attractive. The following proposal originated at NASA's George C. Marshall Space Flight Center (Dr. F. Krause). It is interesting enough to warrant a feasibility test program. If successful, it would be a simple and elegant way to determine world wide atmospheric winds from space and would be of extraordinary significance for tropical meteorology.

The proposed test arrangement employs two passive remote detection systems, which are mounted

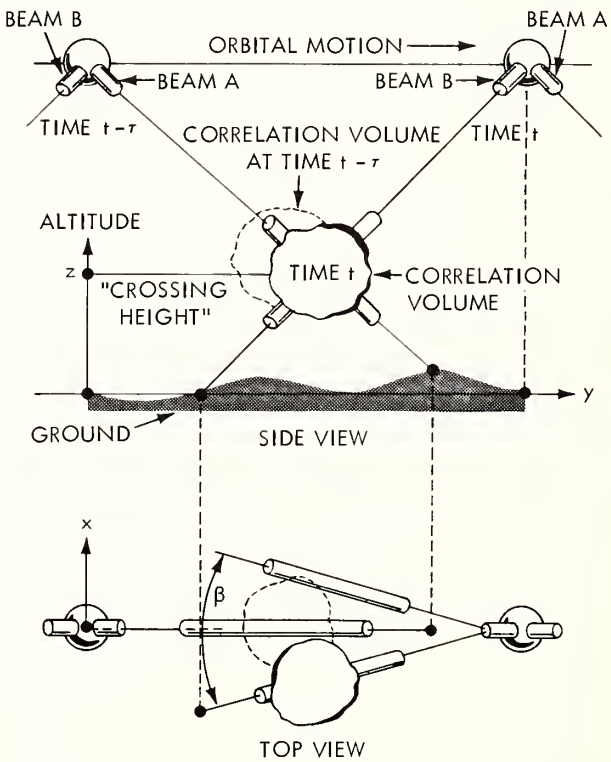

Figure 2.4-9. "Crossed Beam" method for remote measurement of wind. At minimum distance of the two lines of sight, radiative fluctuations in the atmosphere have maximum cross correlations yielding average wind velocity at "crossing height."

on a stabilized platform forming an intersection angle inside the orbital plane, see Figure 2.4-9. The leading detection system monitors the time variation of light emission and extinction processes, which are caused by scanning the space variations of aerosols, ozone concentrations and CO_2 temperatures along its entire line of sight. The trailing detection system may be described as a fan of beams covering a certain azimuth range β. Each beam of this fan is set by another photodetector on the focal plane of the collector optics. The modulations which are received along each beam at time t are then multiplied with the fluctuation which the leading beam saw at the earlier time t - τ. The delayed beam A and the beam fan B intersect at a certain "Crossing height" which is selected by the time delay. Assuming that two non-parallel beams experience common modulation only at the cross height z, local information at this height can be retrieved statistically by supressing the beam modulations at all other heights and the background modulations with a digital, real time cross-correlation routine.

The measurement of wind components follows by considering the displacement of frozen patterns normal to the orbital plane during the lag time τ. Such a displacement will move the light sources, which were encountered by the leading beam, away from the orbital plane and across the trajectories of the fan. The position of the displaced pattern is indicated by a maximum beam correlation. The displacement can thus be found by plotting the beam correlation against the fan angle β and by looking for the position of the correlation maximum. Repeating this procedure for other time delays will give horizontal winds at other altitudes and a complete wind profile can be measured with a single sweep. Analytical studies and experimental wind tunnel results (Krause et al, 1966) indicate that:

(1) Convection velocity, length scale and other parameters may be resolved, normal to the plane of the beams, within limits that are given by statistical errors and the beam diameter (approximately 50 m).

(2) Passive radiation from meteorological modulations within the line of sight provides enough radiative power to give optical signals in excess of external and detector noise levels.

(3) The measured convection speeds are group velocities and will differ from mass average (wind) velocities only if positive and negative fluctuations of the optical signal are not equal. However, wind tunnel experiments under extreme conditions (free shear layers) show that the difference should not exceed a few percent of the wind speed.

In case of mountain induced stationary waves or vortices correct wind values can probably not be expected.

The concept applies equally to the visible, the infrared and the microwave region of the spectrum and might be used to measure flow velocities inside and outside clouds.

At this time tests are planned by NASA to measure winds by a crossed beam system from the ground and to compare them with in-situ measurements on a 400 ft. high tower. These tests will serve to determine the achievable accuracies and the remaining technical problems. It is estimated that an orbital system will require a mirror size of about 1 m^2 in order to extract the desired signal from noise under the non-steady atmospheric conditions.

Until such system becomes available, the above mentioned "GHOST concept" using constant pressure balloons, to be located and interrogated by synchronous satellites, will provide useful wind data for the "World Weather Watch."

2.4.2.3 Ground and Sea Surface Temperatures. At present, numerical models and other methods for short- and long-range prediction and rapidly advancing to the point where they can directly incorporate the effect of heat sources and sinks. For the atmosphere the primary external heat sources are at the interface with the underlying oceans and ground. The energy exchange at the ocean-air interface is one of the governing factors of the general circulation.

Synoptic data on the surface temperature of the globe as required by the World Weather Watch are, at this time, sparse or missing entirely over many oceanic areas. There is hope now that technological problems can be overcome to obtain these measurements from spacecraft. (Regarding a similar need for surface data on snow and ice, see Section 2.4.2.5).

The precise measurement of absolute surface temperature from space is more difficult than that of relative temperature differences because of the radiative contributions of the atmosphere itself. To eliminate or correct for these contributions a very narrow atmospheric spectral window must be used which in turn implies conflicting requirements in available energy and desired ground resolution.

Balloon flight tests with a "SIRS" instrument (Fig. 2.4-8) indicate that utilization of the 11.1 micron spectral window will permit the determination of surface temperatures within about 1 or 2°C.

(Saiedy & Hilleary, 1967). It appears that precise knowledge of the atmospheric structure may not be required. Corrections based on air mass type, geographic region and season should permit the indicated accuracy. The corrections amount to 8°C in very humid tropical atmospheres, and to about 0.5° in arctic atmospheres.

This measurement requires an instrument with relatively large radiance acceptance characteristics. The SIRS spectrometer has a wide (12°) field of view which is not desirable because clouds in the field may seriously interfere with the surface temperature measurements.

A spectral radiometer could be designed especially for the surface temperature measurement with a narrow field of view and a fairly large entrance optic. A 20 milliradian field of view (4 n.mi. resolution from 200 n.mi. altitude) would require a 5 inch diameter optic and a 1 sec. system time constant. A 5 milliradian field (1 n.mi. from 200 n.mi. height) would entail a 20 inch optic with the same system, assuming the use of a thermistor balometer detector.

In the research and development phase surface temperature measurements would be particularly suited for manned operations because the astronaut can aim the instrument through breaks in clouds and calibrate it when required. Cloud top temperatures could be obtained with the same instrument.

Microwave measurements of absolute surface temperature, while in principle not obstructed by clouds, run into problems connected with uncertainties about emissivity and reflectivity of the ground surface.

It appears that the infrared sensor for the measurement of absolute surface temperature in cloud free areas is a step in the right direction and deserves early development.

2.4.2.4 Surface Roughness. The transfer of mass, momentum, and heat at the earth-air interface determines the structure of the atmospheric boundary layer and, in a broader sense, profoundly affects the general circulation of the atmosphere. Therefore, it is vital that detailed knowledge be obtained regarding the physical nature of the lower boundary, particularly some measure of its roughness.

To characterize the roughness of the boundary between the atmosphere and the earth or ocean, meteorologists have long used a parameter called the aerodynamics surface roughness length, z_o. This parameter appears as a constant of integration in the equation which describes the surface-layer wind profile and can at this time only be obtained through an analysis of observed wind profiles at a particular site. This procedure is very costly and time-consuming, and produces estimates of z_o which are virtually point values, representative only of isolated small areas. What is needed is some way of obtaining global maps of z_o which could be used eventually on an operational basis in numerical weather prediction.

Some attempts to estimate region z_o values for continents (Kung and Lettau, 1966; Kung, 1963) have been based on empirical relationships between height of the vegetation and z_o. Information on surface roughness can also be used to determine "land use", a parameter of interest to climatology, heat budget, evapotranspiration, soil moisture, etc.

Recent work with radar scatterometer techniques indicates that surface roughness may be related to variations of radar cross sections obtained from multifrequency (sidelooking) radar as a function of the depression (incidence) angle (Katz, 1966). Figure 2.4-10 illustrates the variation of the quantity a as a function of the depression angle and for different types of surfaces, where $a = k\lambda^a$ and σ = radar cross section (dB), k = constant, and λ = wavelength. Snow surfaces are unique because they show a positive a for horizontal polarization in contrast to other surfaces. Figure 2.4-11 illustrates the variation of radar return with depression angle for different sea states. Strong changes in slope are indicated.

If these measurements can be related to the aerodynamic roughness parameter, multifrequency radar carried by a polar-orbiting space platform could furnish daily global maps of z_o. Also, a climatological survey of this quantity for different seasons could be made.

It is interesting to note that similar requirements exist in oceanography (see subsection 2.6.2.3, Sea State), in the telecommunication sciences (see subsection 2.3.2.5, M, Electromagnetic Properties of the Earth's Surface) and in meteorology (see Table 2.4-A, Surface Winds over the Oceans). Therefore, the same basic equipment could be used to obtain measurements useful to several disciplines of the environmental sciences.

While it is desirable to ultimately know the values of z_o within $\mp$ 10 percent over a 10 mile square area with global coverage about once a day, it is quite doubtful that such accuracies can be achieved in the foreseeable future.

A ground and airborne test program is required to evaluate the radar data against measured wind profiles. High resolution color photography is also potentially useful in determining surface roughness and land use.

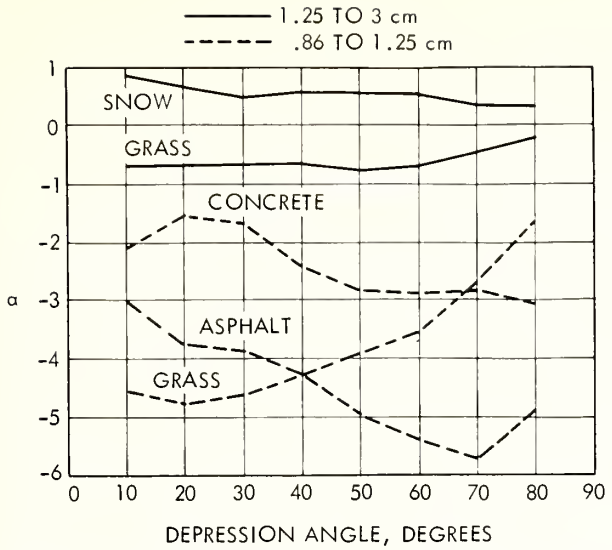

Figure 2.4-10. Multifrequency radar scatterometer. Wavelength dependence of different surfaces as a function of beam depression angle. For the characteristic α see text. Note that only snow has positive α (after Katz, 1966).

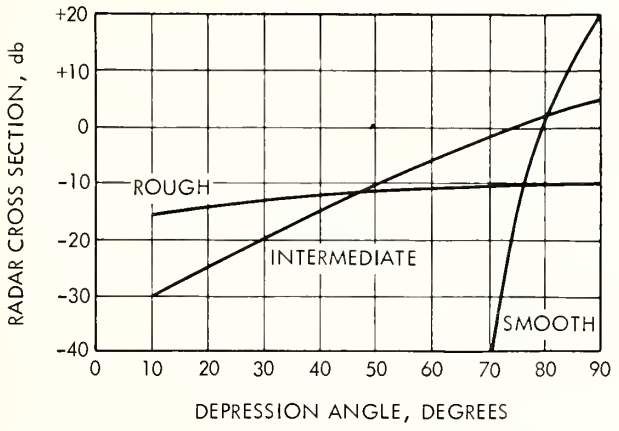

Figure 2.4-11. Radar scattering cross section versus beam depression angle for various sea states (after Katz, 1965).

2.4.2.5 Ice and Snow Cover. Approximately 15,000,000 square miles, or about 10 percent of the earth's surface, is covered with ice. The formation, breakup, distribution, and albedo of this ice cover and meteorologically and climatologically significant, and measurements of these parameters are necessary in any consideration of the earth's total heat budget. The polar regions, because they are symmetrically located with respect to the axis of the earth and to the general pattern of atmospheric circulation, permit and facilitate certain comparisons between variations of heat budget and circulation intensity (Fletcher, 1965). The development of high-speed computers makes it possible to model such large-scale planetary processes mathematically. However, wide year-to-year variations in pack ice extent (an important parameter in these numerical models) are known to occur and have long been associated with abnormal climatic conditions. To test the reliability of these models it is necessary to compare theoretical values continually with observed values. Satellite systems afford an unprecedented opportunity for obtaining values of the required ice parameters.

On a more localized scale, the formation or breakup of ice and on bodies of water of any size signals a change in the type of weather conditions experienced in that region, particularly by stations on the leeward shore. In effect, the climate of a particular region may undergo transition from maritime to continental and back again, depending upon the amount of ice-covered water nearby. During this transition low-altitude aircraft may experience considerable in-flight turbulence.

A great deal of effort is being expended to forecast the regional climatological changes resulting from ice formation and dissipation by means of historical data, temperature degree-days, and aerial reconnaissance to determine the extent of freeze or breakup. However, even relatively small lakes may take several days to freeze or, under the right conditions, may freeze overnight. Because of weather, logistic, and in some cases, economic problems, it is neither feasible nor practical to conduct routine aerial ice reconnaissance over major lakes or bays to observe these changes. Techniques for forecasting formation or breakup of ice, although greatly improved over the past few years, are still only partially successful. Until these techniques can be refined, a satellite system affords the meteorologist a quick and practical method of conducting over-water ice surveys. Information from such a system, when fed back into the ice forecasting program, can be used also to check and improve mathematical methods of forecasting changes in ice conditions.

In any consideration of the earth's total heat budget, as well as in applied short- and long-range weather forecasting, the effects of *snow cover* cannot be ignored. In actual practice, these effects may be harder to anticipate than in the case of ice cover, since variations in snow cover occur much more rapidly than do variations in ice cover. A snow cover as little as one inch in depth may increase the albedo of a given surface from nearly 10 percent to nearly 60 percent. Hemispheric observations of snow cover using existing conventional methods are so nearly nonexistent that values used in experimental numerical weather forecasting models are "best-guess" estimates rather than actual values.

A. Data Requirements

Data of a relatively continuous nature are desired in order to determine the presence or absence of ice and snow, percent of cover, distribution, and type. For planetary scale measurements observations at 24 hour intervals or at a minimum of once per week, with a horizontal resolution of 100 km, are required. On a more localized scale a resolution of 1 km or better would be needed.

B. Research and Development Phase

Color photography, with optimum exposure settings and appropriate filters and microwave imagers, are expected to reveal ice type. Additional photographic sampling with high-resolution (100 m) camera systems should be made also and continued until sufficient data are acquired to allow statistically reliable evaluations of ice type, such as young, medium, or winter ice. The amount of coverage required will vary with season and altitude.

Data from ESSA and Nimbus meteorological satellites are currently being used to provide weekly averages of snow cover over the Northern Hemisphere for extended-range and numerical weather-forecasting purposes. As a check on these observations, conventional snow-cover data obtained in the United States have been compared with satellite-acquired data. Results indicate that, except in heavily forested areas, satellite data give a better indication of the average snow cover boundary than conventional methods. In addition, areas of new snowfall, areas of snow depletion, and significant variations in albedo can be detected quickly and readily, even with the relatively low resolution systems aboard existing weather satellites. With further improvements in these systems, actual values of snow cover extent and albedo can be substituted for "best guess" values, thereby providing a more realistic input to numerical mathematical models.

C. Operational Phase

For operational purposes, sea ice imagery obtained with high resolution black and white television systems should be analyzed on a daily basis. The data, in map form, would be converted to computer program format for inclusion in numerical forecasting models.

The same imagery might also be used by oceanographers in studying ocean currents in polar regions, and by marine interests concerned with sea-ice forecasting for ship routing purposes. These possible uses are discussed in other contexts in sections 2.5 and 2.6.

For operational purposes, snow-cover information obtained from space platforms can be depicted in map forms, incorporated into facsimile-transmitted charts, and also converted from map form to computer program format for inclusion in numerical forecasting models.

2.4.2.6 Weather Modification Experiments. The prospect of modifying our meteorological environment is presently entering a new phase in which hopes are high that positive results can be achieved (National Academy of Sciences, 1966 a).

There are several approaches for experimental weather modification, depending on the meteorological phenomena in question:

(a) In extra tropical cyclones ice clouds (cirrostratus or altostratus "releaser clouds") as well as super cooled water clouds ("spender clouds") may be modified simultaneously to produce maximum effects on frontal precipitation.

(b) Modification or orographic cloud systems such as those forming over mountains and warm water surfaces is particularly promising but requires special techniques, because of the stationary character of the cloud formation. Significant local effects may be produced in many areas of the globe. An example are the snow storms forming downwind of the Great Lakes before the water is frozen.

(c) Modification of severe local storms is concerned with the suppression of hail, tornadoes, and lightning. Here cloud seeding methods might be supplemented by other techniques such as the artificial stimulation of corona discharges for the dissipation of high local electrical fields to reduce lightning.

(d) Experimental modification of hurricanes is directed toward changing the energy and water budget by massive overseeding with the ultimate goal to arrive at a mechanism for hurricane control.

(e) Systematic experiments in modifying convective cloud systems have been carried on for about ten years. Improved statistical controls for these experiments are needed and presently being introduced.

For future intensification of weather modification experiments surveillance of clouds pattern from space may be used in actual field operations, especially in connection with ground radar surveillance. The difficulty in selecting suitable targets for weather modification is illustrated by Figure 2.4-12. In this typical convection picture taken from

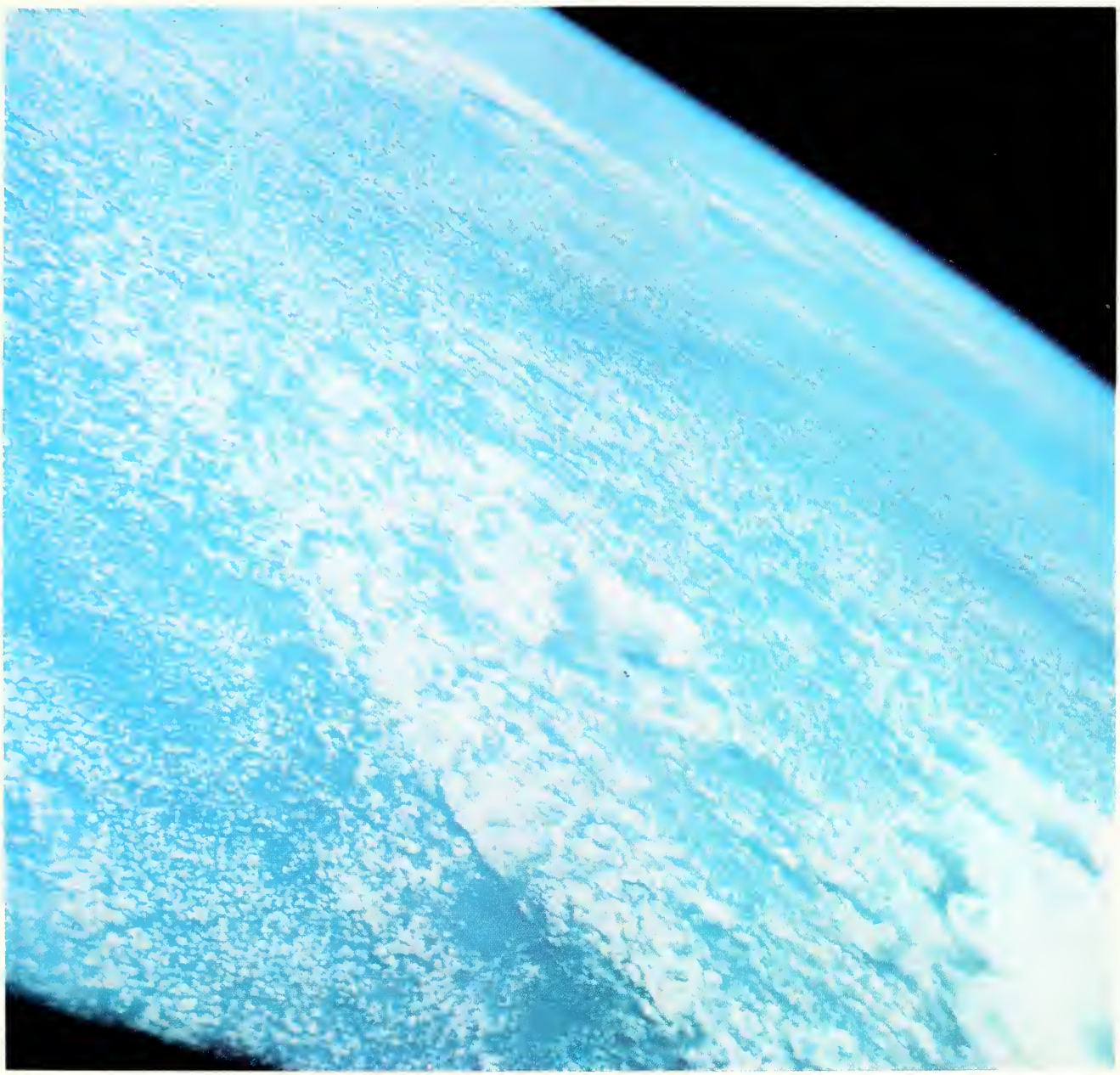

Figure 2.4-12. View from Gemini V spacecraft looking eastward across Alabama, Georgia and South Carolina at 11 A.M. local time on 21 August 1965. All stages of convection from small cumuli to thunderstorms are present illustrating the difficulties of weather modification with "birds-eye" view. (Photo: Astronauts L. G. Cooper, Jr., and C. Conrad, Jr. — NASA).

a Gemini spacecraft, all stages of development, from small cumuli to thunderstorms are present simultaneously. Here an experimental space observer, in communication with the ground, could offer valuable services. At this time it is impossible to obtain comparable views from high altitude aircraft flying at about twice the height of the tropopause (which is also roughly the ceiling of the earth's cloud deck). Assuming a maximum useful viewing angle of 65° from local vertical the practical limitation of aircraft is given by a 25 mile radius, which is about 1/10 of the viewing radius attainable from a spacecraft in low orbit. In other words, the cloud area observable from aircraft and is ideally suited to view mesoscale phenomena (order of magnitude 100 miles).

A complete life history of the cloud and precipitation phenomena should be obtained. Specifically, data are needed on cloud type and organization. It is estimated that this requires a resolution of about 1,000 feet. In addition, electrical activity, precipitation, and cloud top height must be determined. If continuous observations for many hours are necessary, a synchronous orbit should be selected. This implies use of a telescope (Fig. 3.6-6) and a multiple sensing system. A highly trained meteorological observer, in continuous two-way voice communication with the field crew on the ground, is the key to this operation.

Consideration will also be given to large-scale, long-term weather and climate modification. In order to affect appreciably the radiation balance at strategic times, locations and altitudes guidance is needed from mathematical modeling of the atmosphere. One suggested approach is the creation of artificial cirrus layers. Already the injection of water over the jet air routes has lead to wide spread man-made cirrus layers. Radiation measurements in the infrared and solar radiation spectrum from the Nimbus satellite give good evidence of the greenhouse effect connected with extended cirrus decks. Figure 2.4-13 and 14 illustrate this situation; a large opaque cirrus band extends from 25°N to 60°N over the Pacific Ocean and appears as a source of low intensity infrared radiation (Fig. 2.4-13) while the same band is essentially transparent in the solar radiation spectral range (Fig. 2.4-14). Since the source of outgoing infrared radiation is at a much lower temperature than the earth's surface, heat is trapped under the cirrus deck.

Less clear are the possibilities and consequences of modifying the ozone content and temperature of the upper atmosphere by injection of specific chemicals. If such possibilities should develop in the foreseeable future the weight lifting capability of the Saturn-V class carrier rockets may be kept in mind.

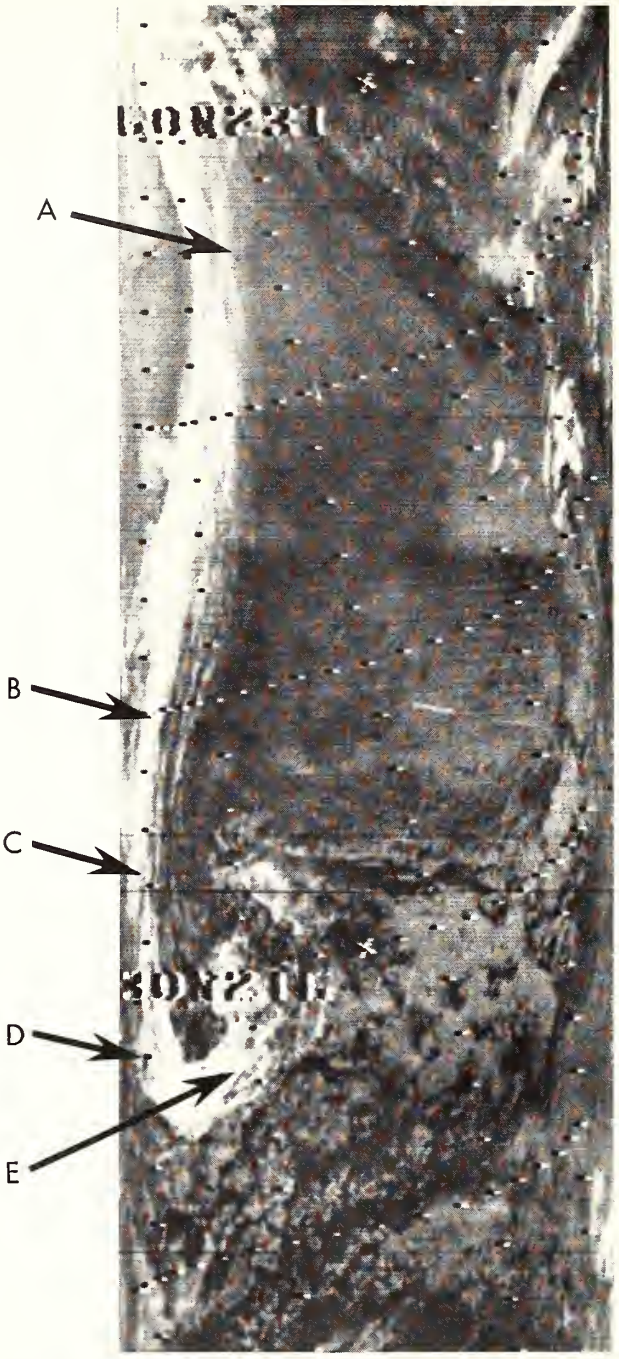

Figure 2.4-13. A high resolution infrared (HRIR) image of the Eastern Pacific taken by Nimbus II satellite on July 12, 1966 at 0930 Z in the spectral range of 3.5 to 4.1 microns. The white band on the left (shaped like a question mark) represents an area of low intensity infrared radiation. It depicts cirrus clouds extending from 25°N to 60°N. Arrows A to E identify points along the cirrus band.

Figure 2.4-14. Mosiac of vidicon pictures of same area taken in visible range of spectrum by ESSA-1 satellite on July 12, 1966 between 2000 and 2400Z. The cirrus band seen on Figure 2.4-13 is identified by arrows A to E and appears almost transparent in the visible spectrum. Comparison of the two figures illustrates the "greenhouse effect" of high level cirrus layers.

2.4.2.7 Tropical Flow and Convection Fields. The equatorial zones are still a major question mark in regard to their precise role in the general circulation and one of the remaining problems of numerical weather prediction. Lack of data is part of the difficulty. Presently operational weather satellites make significant contributions to tropical weather analysis and prediction. The international Global Atmospheric Research Project foresees a field project, the "Tropical Meteorological Experiment" (TROMEX), to shed light on the tropical problem (WMO, 1967; ICSU, 1967). This program is crucial to the operation of the World Weather Watch.

The possibility should be investigated to combine TROMEX with a major space mission, preferably a well planned Saturn-Apollo Application flight. This, in connection with data from other meteorological satellites in synchronous as well as polar orbits may offer the possibility to plan on a real time basis, meteorological reconnaissance flights to investigate in detail the elusive structures of the equatorial zones. Requirements in related areas could be satisfied simultaneously, for example, the oceanographic problems of sea-air interaction, seastate, sea currents and shoal waters (see Section 2.6).

2.4.2.8 Global Cloud Census. A complete census of cloud types (5b of Table 2.4-A) as distributed over the globe has never been made, in fact there has been no possibility to obtain these data. With the advent of the polar orbiting satellite this opportunity now exists, however the horizontal resolution must be compatible with cloud type definition. A 300 meters resolution postulated earlier would be more than satisfactory. The use of cloud top temperature data may help to identify cloud types in doubtful cases.

Such census will be a function of local time and season. Data taken within one day by a polar orbiting spacecraft will fulfill the requirement of identical local time. To achieve different sets of local time and season several surveys have to be taken during a year. Even such a modest program will constitute a major data evaluation problem and early consideration should be given to computer analysis using pattern recognition and other techniques.

2.4.2.9 Atmospheric Electricity. A global survey of *lightning* activity (6a of Table 2.4-A) is basic to the understanding of the maintenance of the earth's electric field. If combined with visual observations it will also reveal information on lightning characteristics not obtainable from the ground. For example, radar measurements have indicated the existence of discharge channels extending over 100 miles horizontally, which may or may not represent visible lightning discharges. Also the question remains unresolved if thunderstorms discharge vertically upwards toward the ionosphere (Cole, Hill, and Pierce, 1966). Lightning can be photographed and recorded during daytime using a narrow spectral band around the H_a line (6563 A) which is practically absent in the solar spectrum due to absorption in the solar atmosphere (Coroniti, 1966).

Sferics measurements in the VLF, HF and VHF range are desired to supplement those already programmed by NASA in the UHF range. Knowledge of the geographic distribution of lightning will contribute to the radio-noise survey discussed in Section 2.3.2.4.

It is also desirable to make a serious attempt to measure the three components of the *electric field* in the upper atmosphere and ionosphere and their variations with time (6b of table 2.4-A). It remains to be seen if truly electrostatic sensors can be used to measure fields in the micro to millivolt/meter range. (For other possibilities, see 2.3.2.5-C, under "Aeronomy and Telecommunications").

2.4.2.10 Proposals for Future Consideration. Table 2.4-A lists numerous additional proposals. Some of them require major technical development, others appear technically feasible, but are of lower priority in the light of the selection criteria, listed in Table 2.1-B. The intention of the task force was to focus interest on a few major items rather than on a great variety of proposals. Nonetheless it is felt that consideration should be given to the following requirements:

A. High Resolution Imagery

So far satellite meteorology has been concerned primarily with cloud imagery. A wealth of experience has been accumulated in the interpretation of cloud pictures based on a resolution of the order of a few miles (Anderson, Ferguson and Oliver, 1966). At the same time NASA's extraordinary "Gemini" photographs taken by the astronauts under the "Weather Photography Experiment" (Nagler and Soules, 1965) have proven the value of high resolution photography for meteorological research and operations.

It is, therefore, not surprising that high resolution cloud imagery is a common requirement from many meteorological quarters. At this time it appears that a resolution of about 300 meters is desirable. This is about an order of magnitude better than present

satellite television pictures. For daily global monitoring such resolution represents a hundred fold increase in data points and, therefore, a considerable data handling problem.

The value, however, of this high resolution lies not in the routine use, but in the possibility to clear up doubtful areas and to "zoom in" on points of special interest.

There are several ways to implement this requirement. For research purposes the photographic assembly described in 2.7 would be more than satisfactory. For operational use high resolution scanning devices or much improved vidicon systems would be needed. Also film may be made available at the ground with a minimum of delay using reentry capsules or on-board development/transmission ("lunar orbiter") techniques. Versatile display devices are needed by the user to take full advantage of the data; for example, a capability should be provided to combine large area projection with the option of high resolution zoom at arbitrary target areas.

Meteorological applications of high resolution imagery are multifold. Examples are: the interpretation of critical or doubtful cloud areas with respect to jetstream and turbulence characteristics (Table 2.4-A, proposal 3a); cloud type (5a and b); cloud structure in squall lines and hurricanes (3d and e); organized convection pattern (5c); ice vs. water clouds (5d); precipitating areas (8a); and mountain waves (3e).

Additional requirements not directly connected with cloud interpretation may also be satisfied by high resolution imaging systems, for example estimate of surface roughness and land use (2c), precise determination of snow lines (2d); see also Subsection 2.5.2.2), the detection of forest fires (3b), air pollution plumes (9b, d; see also section D below), flood expanse (3c) and possibly soil moisture (2f).

B. Solar Constant

It has been estimated that the solar constant (7a of table 2.4-A) as determined by earth based measurements is known only to 5 percent, one percent of which may be attributed to uncertainities in radiometric standards, the rest to atmospheric absorption and technological problems. Specifically an uncertainty of 20 to 30 percent exists in the 2,000 to 4,000 Angstrom spectral range. Balloon borne radiometer measurements also have indicated the possibility of significant year-to-year variations of the solar constant. Estimates of its value range form 1.90 to 2.05 cal. cm^{-2} min^{-1}.

New attempts to measure the solar constant from above the effective terrestrial atmosphere are recommended employing total and filter radiometry with 0.1 percent precision. Preliminary tests, using B-57 and X-15 aircraft (Jet Propulsion Laboratory and Eppley Laboratories) have demonstrated the feasibility of the measurement. It is hoped that in this way one of the most important quantities affecting the earth's climate will finally be determined (Drummond, 1965).

C. Albedo of Clouds and Ocean Surfaces

One factor determining the amount of solar radiation available for heating the atmosphere and the oceans is the quantity of incoming radiation not reflected from cloud tops and ocean surfaces. Little is known about the precise albedo values of oceans and clouds as a function of sea state, cloud type, incident and scattering angle (7b of Table 2.4-A). Current measurements do not permit adequate determination of these variations in albedo and an isotropic assumption is made in determining total reflected energy flux. It is therefore, recommended to measure the albedo in the 0.2 to 0.6 spectral range with an accuracy of 1 to 2 percent in angular steps of 10° over areas of about 25 miles diameter.

D. Air Pollution

There is a growing requirement to detect and locate air pollution hazards and to improve warning systems and techniques to ensure prompt initiation of control measures. Through high resolution imagery coupled with developments in sensing techniques for specific pollutants, a potential surveillance capability may be achieved which could also gain significance for visibility surveys. Absorption spectroscopy, polorimetry, and Lidar (optical radar) have potential applications in this direction.

2.4.3 Related NASA Program

The basic goal of the NASA meteorological program is the development of space technology to provide data to increase our knowledge and understanding of the Earth's atmosphere, and thereby improve our ability to forecast the weather. Particular emphasis is, then, on the requirements of the meteorological services in weather analysis and forecasting. Such data are also useful for meteorological research. The program consists of an orderly succession of studies, background supporting research and technology,

development of specific flight experiments, R&D flights, and where applicable, development of operational systems.

A. TIROS and Nimbus Based Systems

Past "TIROS" and "Nimbus" flights provided the technological foundation for meeting interim operational requirements of operational data users. The ESSA funded "TIROS" Operational Satellites which are presently flying ("TOS system") are based on this technology. The "TIROS M" mission planned for 1968 will advance the state of technology required for identifying and tracking weather systems both day and night in preparation for a more advanced operational meteorological satellite ("Improved TOS"). The "TIROS M" spacecraft is a relatively low-cost, light-weight platform for flight testing selected and simpler advanced sensory systems.

The more complex technology required for fully operational quantitative measurements of the atmospheric structure will probably evolve from the research and development flights of the heavier and larger "Nimbus" spacecraft. The satellite system required for the World Weather Watch Program will be an outgrowth of the technology developed by this series of spacecraft.

B. Meteorological Systems at Synchronous Altitudes

In order to provide the capability for continuous observations of the atmosphere and its short-lived processes, research and development, for meteorological satellites at synchronous altitude are underway. The initial experiments are being conducted aboard the "Applications Technology Satellites." They are directed toward obtaining continuous cloud cover data and relatively low resolution radiation data and determining the effect of sensor motion on the stabilization of the satellite. Based on these experiments the development of a Synchronous Meteorological Satellite System is expected. First results with a high resolution scan camera on board the ATS-1 synchronous satellite are most encouraging.

C. Meteorological Experiments on Manned Spacecraft

Manned spacecraft will be used whenever it is appropriate to test sensors and techniques for obtaining global quantitative measurements of the atmosphere. Experiments are under consideration for flight test on the Apollo Applications missions. The Manned Space Station Study Group is evaluating the use of these large, permanent spacecraft for carrying the very highest resolution sensors from UHF detectors through millimeter wavelength radiometers and radar scatterometers. Spacecraft and sensors related to the NASA program in Meteorology are as follows:

Nimbus B (1968)

Instrumentation	Application
Interferometer Spectrometer	Temperature Profile
Satellite Infrared Spectrometer	Temperature Profile
High Resolution Infrared Radiometer (Day/night)	Cloud cover
Image Dissector Camera System (Day)	Cloud Cover
Interrogation, Recording & Location System	Wind Velocity, Moisture, Temperature, Pressure, etc.
Monitor of Ultraviolet Solar Energy	Solar UV
Medium Resolution Infrared Radiometer	Heat Balance

Nimbus D (1970)

Instrumentation	Application
Infrared Interferometer Spectrometer	Temperature and Water Vapor Profile
Satellite Infrared Spectrometer	Temperature and Water Vapor Profile
Selective Chopper Radiometer	Temperature Profile
Backscatter Ultraviolet Spectrometer	Ozone Profile
Filter Wedge Spectrometer	Water Vapor Profile
Sferics Detector	Sferics
Interrogation, Recording & Location System	Wind Velocity, Moisture Temperature, Pressure, etc.
Image Dissector Camera System (Day)	Cloud Cover
High Resolution Infrared Radiometer (Day/night)	Cloud Cover
Monitor of Ultraviolet Solar Energy	Solar UV
Cloud Altitude Radiometer	Cloud Top Height

TIROS M (1969)

Instrumentation	Application
Advanced Vidicon Camera System (Day)	Cloud Cover
Automatic Picture Transmission Camera System (Day)	Cloud Cover
High Resolution Infrared Radiometer (Day/night)	Cloud Cover
Flat Plate Radiometer	Heat Balance

***Applications Technology Satellite ATS-C (1967, Earth Synchronous Orbit)**

Instrumentation	Application
Image Dissector Camera System (Day)	Cloud Cover
Spin Scan Color Camera (Day)	Cloud Cover
Omega Position Location Experiment	Data Collection

Applications Technology Satellite ATS-D (1968, Earth Synchronous Orbit)

Instrumentation	Application
Image Orthicon Camera System (Day/night)	Cloud Cover

*Launched November, 1967.

Apollo Applications "AAP-A" (1970)

Instrumentation	Application
Dielectric Tape Camera System (Day)	Cloud Cover
Image Orthicon Camera System (Day/ night)	Cloud Cover
Visible Radiation Polarization Measurement	Atmospheric Composition
Stellar Refraction Density Measurement	Density Profile
Infrared Temperature Sounding	Temperature Profile
Infrared Temperature Profile Radiometer	Temperature Profile
Infrared Interferometer Spectrometer	Temperature and Water Vapor Profile
Filter Wedge Spectrometer	Water Vapor Profile
Multi-channel Radiometer	Earth and Cloud Top Temperature
Integrated Passive Microwave	Temperature Profile
	Moisture Profile
	Earth Temperature
UHF Sferics Detector	Thunderstorm Detection

2.5 HYDROLOGY

2.5.1 Description of Scientific Field Considered

Hydrology, as defined here, is that branch of the environmental sciences most directly concerned with the effects of precipitation and evaporation upon the quantity, quality, physical state, and areal and vertical distribution of water above, on and below the land surface. Hydrology is also concerned with the origin, distribution, and properties of the waters of the earth. By its very nature, hydrology is interlocked intrinsically with many other disciplines, particularly meteorology, geology, geography, oceanography, hydraulics, civil engineering, soil conservation and forestry.

ESSA has the responsibility for river and flood forecasting and warning (Figure 2.5-1) and for providing certain hydrological information required by others for water inventory, water resources management, and minimum flow control. Most of this information is collected through a network of private citizens and cooperative reporting stations managed and controlled by the Weather Bureau and other agencies. Substantial financial support and direct assistance are provided by other Federal, State, and local governmental agencies. River and stream flow gages, snow surveys, rain gages, radar sites, and aerial surveys are integral parts of the total data-collection network.

For forecasting as well as for research, hydrologists must be concerned with virtually all phases of the hydrologic cycle. This necessarily implies a knowledge of hydrometeorological processes (location, type, and intensity of all forms of precipitation); an inventory of surface water (storage in rivers, lakes, and reservoirs, or as snow or ice, and surface water discharge from these storage areas); an assessment of ground water storage (in aquifers); and calculations of water volumes released into the atmosphere through evaporation and transpiration (water loss from plants and soils).

Since river drainage systems generally do not conform to political boundaries, the hydrologic organization scheme divides the United States into several drainage basin areas, each with its own river forecast center, and each with its own peculiar forecasting problems. River forecast centers cover only about 75% of the United States today. Common to all these, however, is the problem of obtaining adequate, accurate observations over the entire basin area at the proper time or time intervals to permit accurate forecasting. Many sectors of a river basin may be uninhabited or inaccessible by roads or power or communications lines. These factors make it economically unfeasible to establish an adequate

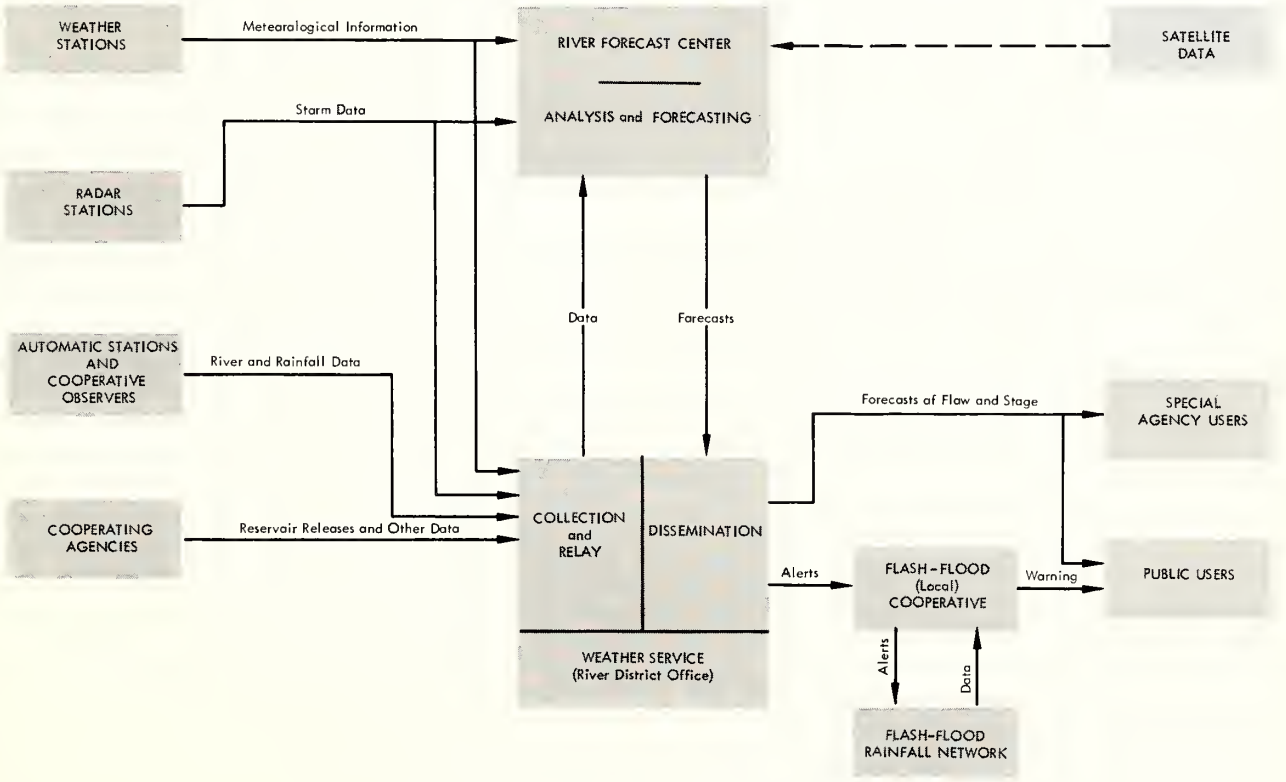

Figure 2.5-1. ESSA river and flood forecast opeations chart.

hydrologic observation network. Satellite systems, with the multiple capacity to observe and to collect hydrologic data could become the vital organs of a total system for data acquisition, analysis, forecasting, and finally, for redistribution of the complete spectra of hydrologic information to focal points for warning, guidance, and decision-making. The global aspects of such systems suggest excellent opportunities for international cooperation.

2.5.2 Proposals and Related Requirements

2.5.2.1 Scope. Six proposed hydrologic experiments presented for consideration are shown in Table 2.5-A. Three are based both on the need for hydrologic information and on experimental work already performed with TIROS, Nimbus, and ESSA data. These include measuring snow cover (Proposal 1a) and characteristics, river and lake ice distribution (2a), and river and lake water temperature (2b). A fourth, communication of data on river level stage (3) and other hydrologic information, is an integral part of an experiment being conducted this year utilizing one of the Advanced Technology Satellites (ATS-B). These four proposals are given highest priority because of their relative simplicity, compatibility with other experiments, and nearly-immediate applicability. Proposals for future consideration include measuring or determining soil moisture, depth of frozen ground, flood expanse, and observations of those snow characteristics which cannot, at least at this time, be considered as priority experiments.

2.5.2.2 Snow. Measurements of the amount of water stored in the form of snow, and effective control of snowmelt runoff from the snowpack, are of major importance in river flood and water supply forecasting, as well as in any successful water conservation and management program. Seasonal accumulation of precipitation or water equivalent of snow on the ground are observed at about 3,000 points in the United States, particularly in the western portion of the country. Aerial surveillance and photography of snow fields complement this network.

Despite the cooperative efforts of many agencies, the over-all network of reporting stations and facilities is still very sparse. Many stations are located in or near major population centers, usually in valleys or near relatively large rivers. Ground observations at remote mountain sites are contingent upon prevailing weather conditions, as are aerial photographic and surveillance missions. Aerial or ground surveys requiring movement of men or equipment are expensive and infrequent. Aerial surveys cover only selected areas and are not comprehensive. Ground surveys are laborious, not synoptic, and rarely made more than once per month. Added to this is the problem of obtaining sufficiently representative measurements over an area

Table 2.5-A — List of Proposals for Hydrology

Proposal Number	Description	Special Orbits
1	Snow	Polar or high inclination
*(a)#	Cover	
*(b)#	Albedo	
*(c)	Temperature	
(d)	Depth	
(e)#	Water equivalent	
*2	Rivers and lakes	Polar or high inclination
(a)	Ice Distribution	
(b)	Water temperature	
*3#	Hydrological information (via communications)	Synchronous
4	Soil moisture	Polar or high inclination
5	Depth of frozen ground	Polar or high inclination
6	Flood Expanse	Polar or high inclination

#Requirements of major importance *Proposals selected for detailed discussion

sufficiently broad to permit accurate description of the snow regime.

Routine observations from orbiting space platforms, obtained daily during periods of rapidly changing conditions, and weekly or at less frequent intervals during more stable periods, could substantially augment conventional hydrologic station reports, providing a much better basis for hydrologic forecasting. Snow cover area, density, depth, albedo, liquid water content, water equivalent, and snow surface temperature are parameters to be measured. Of these, snow cover, albedo, and snow surface temperature are considered the three parameters most easily measured from satellite altitudes at the present time. These are discussed below. The remaining four are no less important, however, and remote sensing of these may be possible by either direct or indirect methods at a later time. In particular, snow depth may be a fourth parameter which can be indirectly measured or estimated from space. This is discussed under Section 2.5.2.6, Proposals for future consideration.

Systematic mapping of areal *snow cover* in individual river basins to an accuracy of 5 percent over a 100 square mile area is required. In mountainous areas delineation of the elevation of the snowline to within ±500 feet is required. Routine observations, obtained once per day during periods of rapidly changing conditions, and once per week at other times, would be necessary. The needed photographic resolution and frequency of coverage to satisfy these requirements were nearly achieved by television imagery obtained at or near perigee from Nimbus I (Figure 2.5-2). Results of a contract study of TIROS and ESSA photographs to determine the feasibility of mapping snow cover boundary from satellite altitudes (ARACON, 1966) revealed that in non-forested areas an accuracy of ±20 miles could be achieved. The elevation of the snowline shown in a Gemini V photograph of a mountainous area in the Himalayas (Figure 2.5-3) was determined to lie between 18,000-19,000 feet. The area photographed on the Gemini V mission is shown in the insert in Figure 2.5-4, a TIROS V picture covering a much broader area but with much poorer resolution.

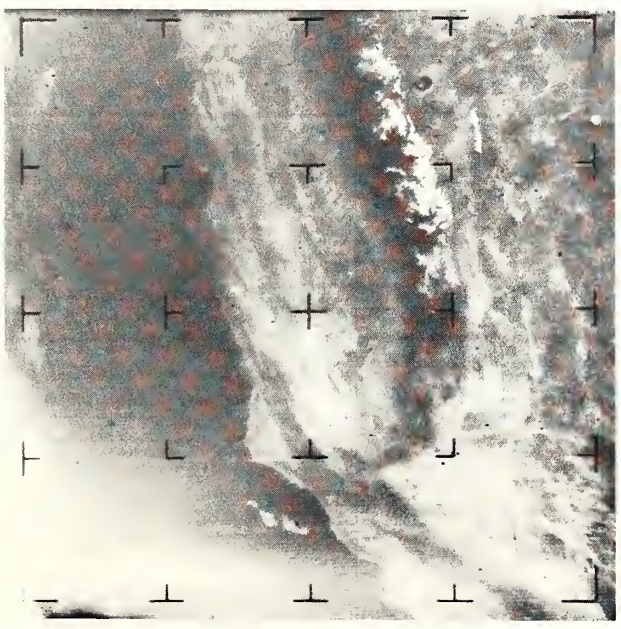

Figure 2.5-2. A Nimbus I Advanced Vidicon Camera System (AVCS) photograph of snow on the Sierra Nevada mountains. River and flood forecasting depends upon a knowledge of areal snow distribution.

Higher resolution TV camera systems and improvements in feature identification and grid accuracy would provide better results. Even results to date, however, indicated that a better delineation of actual snow boundaries could be accomplished with satellite data than with existing ground information in areas not covered by dense vegetation.

Snow cover mapping for hydrologic purposes would require the use of high resolution camera systems and a high degree of spacecraft stability to facilitate location and gridding of imagery received. Microwave imagery or scanning systems may also be applicable if such systems could meet the proposed resolution requirements.

Snow cover data obtained for hydrologic purposes would also be applied to extended and numerical weather forecasting.

Albedo of snow pack to an accuracy of 2 to 5 percent averaged over a 100 square mile area is required. Knowledge of the albedo of the snowpack provides an indication of the capability of the snow to absorb or reflect incoming solar radiation, that is, a decrease in albedo leads to greater absorption and consequently acceleration of snow melt. To emphasize the importance of measuring albedo it should be pointed out that the normal range of albedo leads to a difference factor of 6 between the maximum and minimum amounts of solar radiation absorbed by the snow.

In the visible spectrum, variations in the albedo of snowfields caused by differences in vegetation, rising temperatures, rain or snow, and abrupt changes in elevation have been observed in meteorological satellite photographs (Figure 2.5-5).

Snow surface temperature to an accuracy of 3°C averaged over a 10 square mile area is required for snowmelt forecasting purposes. Of particular inter-

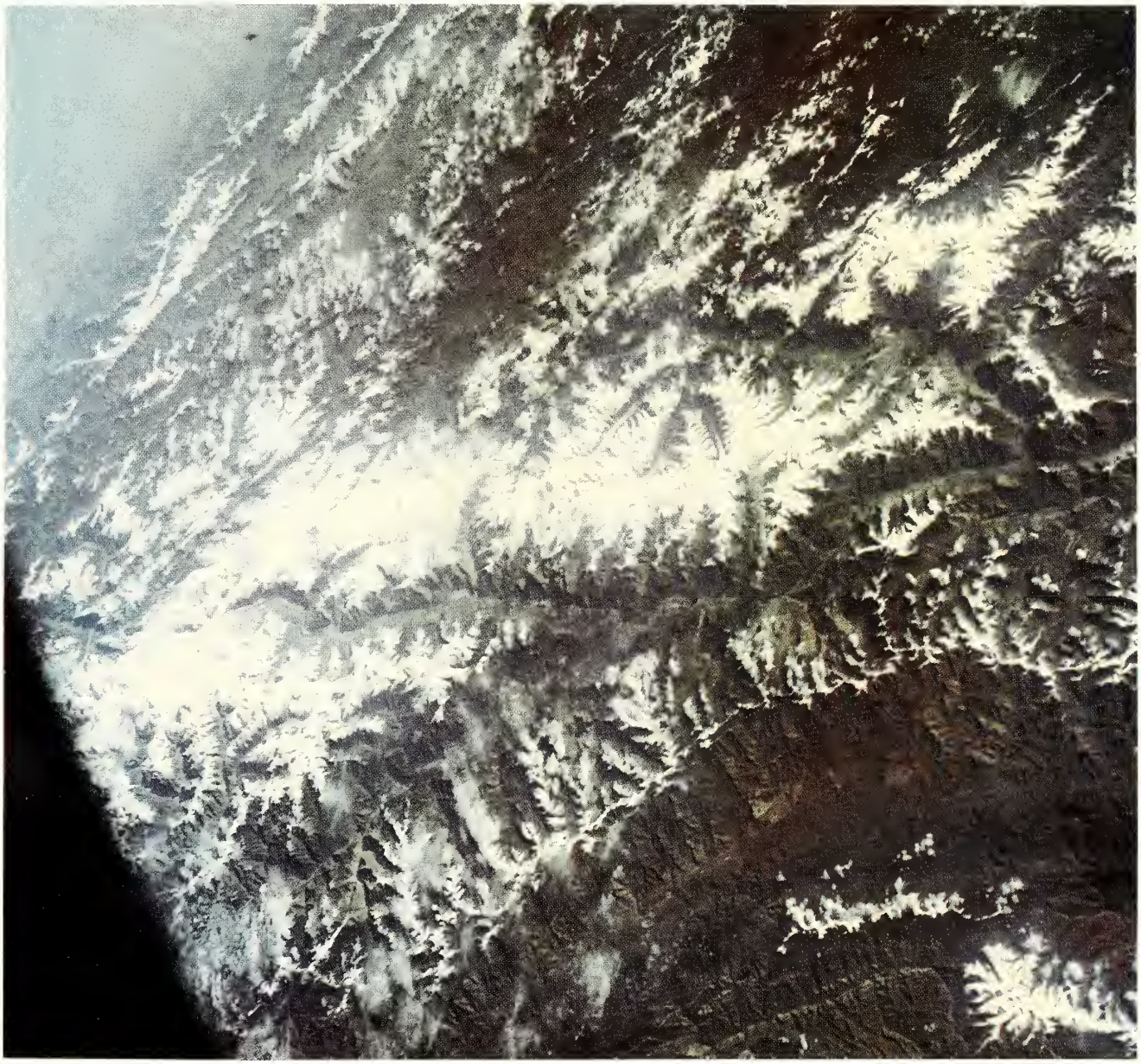

Figure 2.5-3. The elevation of the snow line, as determined from the Gemini 5 photograph of the Himalayas, lies between 18,000 and 19,000 feet.

Figure 2.5-4. The enclosed area in this TIROS photograph is the same area shown in figure 2.5-3. Resolution of this type is of marginal value for hydrological purposes.

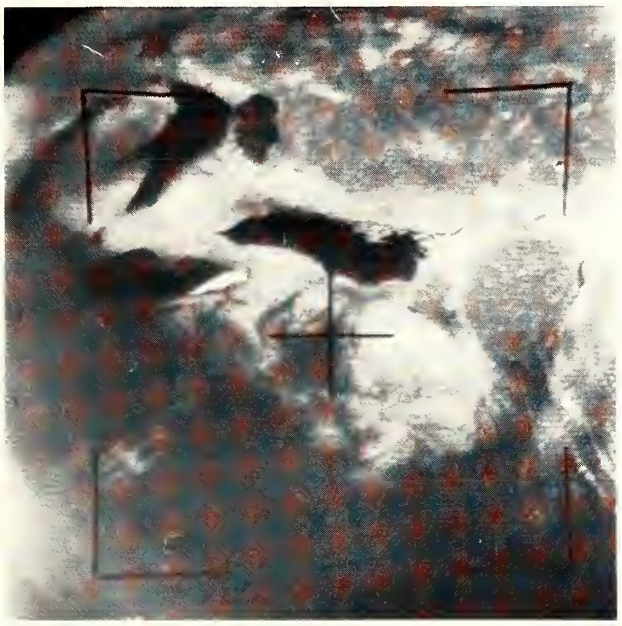

Figure 2.5-5. TIROS VII, April 4, 1964. The bright area in eastern Lake Erie (left of center) is ice near Buffalo, N. Y. The surrounding snowpack shows definite indications of melting.

est are temperatures at or near 0°C. Observations at 12-hour intervals, preferably at or near periods of maximum heating or cooling, are desired.

Alternate heating and cooling of the snow surface produces a change in the density of snow. This change affects the rate of heat exchange by radiation, convection, and condensation between the snowpack and the atmosphere, consequently influencing the air, water, and heat permeability and diffusivity of the snowpack itself. A knowledge of surface temperature therefore provides a direct indication of whether the snow is at a temperature where melt can occur, makes it possible to infer surface conditions (crusting, stratification, etc.), and permits computation of heat exchange for snowmelt forecast purposes. Except at research sites, snow surface temperatures are inferred from actual air temperature and heat balance estimates.

The analysis of infrared data currently available from meteorological satellites indicates that the temperature at the earth's surface can be measured to an accuracy of 1-2°C, or better, depending upon meteorological conditions.

2.5.2.3 River and Ice Lake Distribution. A knowledge of the distribution of ice in river and lake systems is important for flood forecasting and predicting ice formation. Most observations of ice conditions on those lake and river systems of concern to the hydrologist are made at ground stations by paid cooperative observers or at certain Federal, State or local government installations. This network is essential, but necessarily confines observations to single points.

Systematic coverage of ice conditions in these water systems is needed to complement the surface observer network. Information on type and depth of ice, and presence of ice jams, is required. Ground resolution of 500 feet, preferably at synoptic times, is most desirable. The nature of these phenomena necessarily restricts observational requirements to certain seasons of the year.

Extensive work in the interpretation of satellite ice imagery has been conducted over the past several years with TIROS, Nimbus, and ESSA data (Project TIREC, 1963). This work has been confined to large bodies of water because of the resolution of existing camera systems. Even with these relatively low resolution systems, however, ice on major lakes, rivers and reservoirs has been detected.

One major handicap in utilizing visual satellite imagery is the inability of the system to record ice in the very early stages of formation. Microwave radiometers appear especially applicable to the solution of this problem judging from present laboratory results. Radar may be equally useful, keeping in mind that the use of any high resolution system will require a high degree of space platform stability in order to locate and identify the specific parameters being observed.

Observations of river and lake ice conditions relate also to oceanographic requirements for observations of ice conditions since in many cases both disciplines require the same geometric and time resolution. A by-product of these observations would be their application to numerical and extended weather forecasting purposes (see also Sections 2.4 and 2.6).

2.5.2.4 River and Lake Water Temperatures. The temperature of the water surface is used to calculate evaporation and to predict formation and melting of ice on lake, river, and reservoir systems. Temperatures below the water surface to a depth of several meters are also desired. Except at certain research stations, water temperatures are either collected infrequently or not obtained at all. For accurate computation and prediction purposes, the mean water temperature of lakes and large rivers to an accuracy of 1°C over 100 square mile increments at 12-hour periods, preferably at synoptic times, would be required. Over large water bodies surface temperature measurements to an accuracy of 1-2°C have been derived from infrared (IR) observations from meteorological satellites. Increased resolution of IR systems and refinements in IR instrumentation are yielding more accurate measurements of surface temperatures from space altitudes. However, while sensitivity of instruments has been increased to the point where useful temperature values are being obtained, resolution is still too low for most hydrologic purposes.

Experiments to measure surface temperature relate directly to many other requirements for temperature observations, particularly in meteorology and oceanography.

2.5.2.5 Hydrologic Information. An extensive network of stations for reporting river levels exists within the conterminous United States and in other countries of the world. However, relay of hydrologic information from these stations to data collection and analysis centers is one of the major problems of the hydrologist today. Economic factors often preclude use of advanced communications systems over such a relatively extensive network. Establishment of remote, unmanned hydrologic stations in critical observation areas is restricted to a large extent both by economics and terrain. Line-of-sight communications in mountainous areas frequently involves circuitous routing with expensive relay facilities and substantial time delays.

Satellite interrogation of river gaging stations and transmission of this information to selected data centers would be a major breakthrough in hydrologic data collection for river and flood forecasting, since it would provide an essentially instantaneous report of river levels over entire basin areas. Observations at 6-hourly intervals would provide sufficient warning of potentially dangerous flood events in most cases, although for points on small headwater streams, more frequent observations would be desirable. The accuracy of such observations would be contingent entirely upon the accuracy of the gaging device and the telemetry converter.

An experiment involving satellite interrogation river and/or rain gages at four locations in the United States was included on the Advanced Technology Satellite (ATS-B) launched in December 1966. If successful, this experiment will demonstrate the feasibility of a relatively low-cost method of obtaining completely synoptic observations from a large number of river and stream gaging stations.

2.5.2.6 Proposals for Future Consideration.

A. Snow Depth

Snow depth measurements to an accuracy of 8 to 10 percent when averaged over 100 square mile areas are required. Measurements made along snow courses or at hydrologic stations give point measurements of snow depth and presently are the major source of observations of this type. Although extreme care is taken in selecting the location of measurement sites, the characteristics of the site, in terms of vegetation, exposure, slope, etc., vary to such an extent even over small drainage areas that the measurements reflect a quantitative value of snow depth only at a given point.

A contract study of satellite photographs over relatively flat terrain indicated that snow depths between 1 and 6 inches could, in general, be distinguished from areas with heavier snow accumulation, largely from the different appearance of such areas in satellite photography. Multi-sensory instrumentation, including use of microwave and radar techniques, may provide a direct method of obtaining quantitative snow depth measurements, especially in areas of heavy accumulation.

B. Soil Moisture

Soil moisture measurements can be used to estimate runoff from rainfall – the wetter the soil, the greater the amount of runoff. At present, estimates of soil moisture for streamflow forecasting are indirectly derived by formula using antecedent rainfall amounts as a key parameter. In experimental areas soil moisture may be measured by weighing soil core

samples or by using electrical or nuclear devices. An improved method of determining soil moisture distribution is essential for improved surfaces runoff prediction, for more accurate river and flood forecasting, and for hydrologic design criteria.

A knowledge of soil moisture distribution in depth to the nearest 5 percent is desirable. However, knowledge of moisture content in the surface layer would partially meet this requirement because the values could be averaged over approximately 100-square mile areas. Observations over the conterminous United States and later over the entire land surface of the earth, at the same observation time each day for an indefinite period, are required.

The use of airborne passive microwave radiometers and radar to measure depth of soil moisture content is currently being investigated. Estimates of soil moisture may also be obtainable by measuring plant canopy temperatures, or by using black and white, color, or infrared photography to determine plant vigor. Canopy temperatures of certain plants may appear higher or lower than ambient air temperatures depending upon soil moisture conditions. Both a Gemini photograph obtained over Texas and a Nimbus I photograph (Figure 2.5-6) of the eastern U. S. showed a variation in foliage and vegetation vigor due to differences in rainfall.

C. Depth of Frozen Ground

The depth of frozen ground, permanent as well as semipermanent, affects surface runoff of precipitation and necessarily affects river and flood prediction and warning. No formal program exists for determining the depth of frozen ground in each river basin of the conterminous United States.

Systematic observations of frozen ground in in selected areas at the same observation time each day during the winter months is desired. Frost depth measurements to the nearest inch are desir-

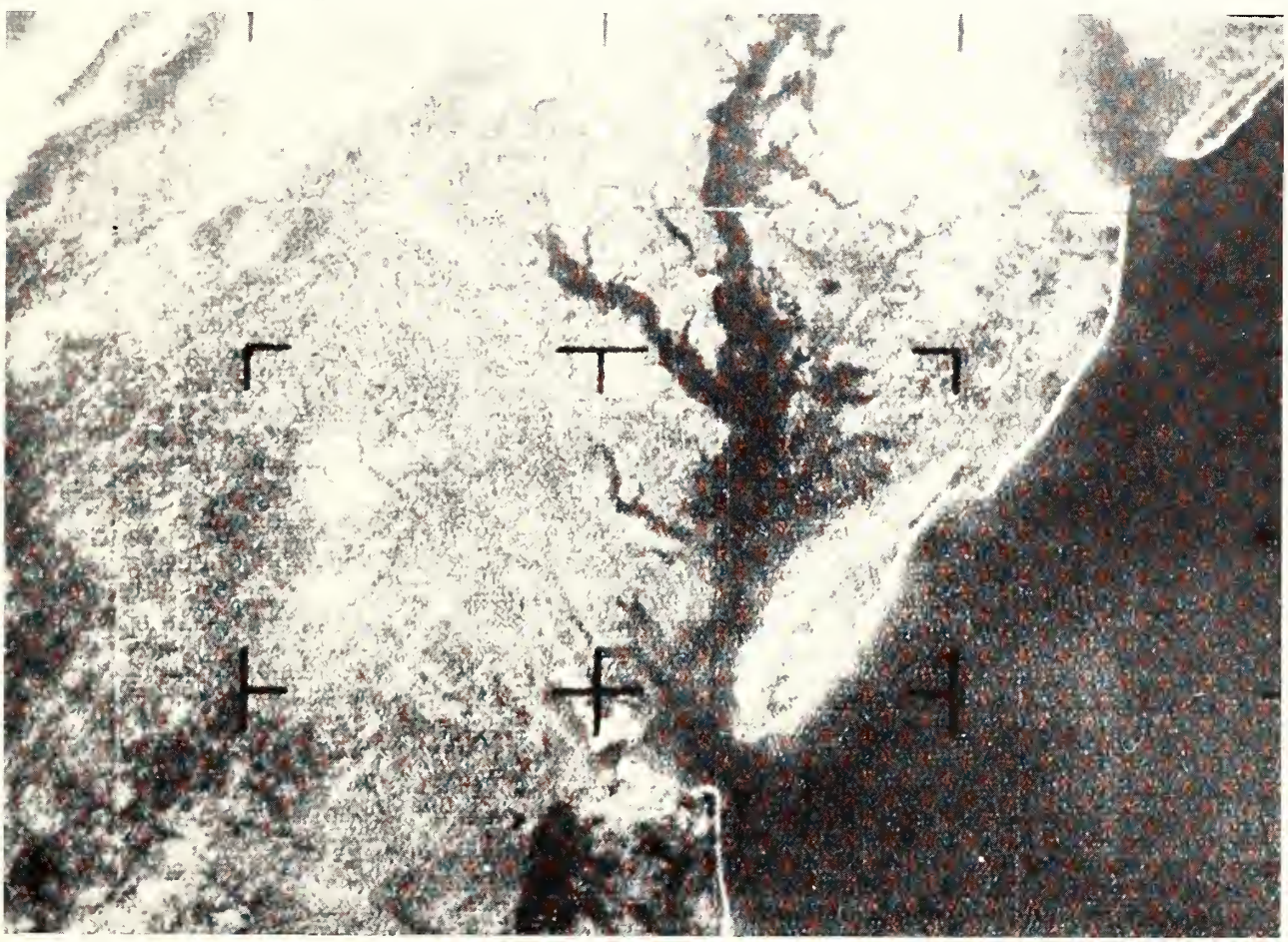

Figure 2.5-6. A Nimbus I photograph of Washington, D. C. and surrounding areas. The area south of Washington has received considerable rain, while almost no rain has fallen north for several days. Vegetation to the south appears darker (and more green) while to the north yellows and browns predominate (the lighter areas).

able, although reports of conditions of the surface layer – whether frozen or unfrozen – would be useful and would satisfy this requirement partially. For realtime use observations at standard synoptic times would be preferred.

Passive microwave studies of frozen soils are being conducted by private industry under the sponsorship of the Department of Defense. However, considerable research will be required before remote detection of frozen ground is feasible by means other than the surface expression as shown by aerial photography.

Observations of the depth of frozen ground relates to meteorological requirements for determining surface conditions for forecasting purposes and for studying broadscale climatological effects.

D. Flood Expanse

During major flood events the extent of flooding should be determined quickly and frequently in order for corrective measures to be taken to warn and prevent additional flooding. Observations of flooded areas are required also for damage assessment purposes and for upgrading future protection and warning systems. Present methods for determining flood expanse are almost totally inadequate, and no practical method for conducting truly synoptic surveys of flooded areas has been developed. For this reason, no formal program has evolved.

Photographic mapping of flood events, utilizing both infrared and visual photographic methods, would be necessary for rapid flood-damage assessment, providing that these data could be transmitted immediately to selected ground sites. Six-hourly observations, both day and night, would be required during the flood period. Area coverage necessarily should include all major river systems of the world, particularly where flooding constitutes a major hazard to populated areas. For both immediate flood prediction and damage assessment purposes, ground resolution of 300 feet would be desirable.

High resolution telescopic observations of flooded areas on an hourly basis would complement photographic coverage and indeed would provide a safety factor for human life. Direct communication of this information to rescue centers in the flooded area would be essential.

Both photographic coverage and real-time communications with ground stations would require extensive crew activity at critical, essentially unscheduled, periods. Six-hourly observations would also require a very high resolution system from an earth synchronous satellite, or several satellites in orbit at the same time.

Since extensive cloud cover is often associated with flood conditions, these experiments were considered highly desirable but somewhat doubtful with regard to results unless or until a system is developed to observe flood events through cloud cover from high altitudes.

2.5.3 Related NASA Programs.

The objective of NASA's program in hydrology is to determine the advantages of conducting hydrologic and water resources surveys from space relative to the following:

- Development of new techniques for hydrologic observations.
- Improved understanding of the global magnitude of hydrologic phenomena.
- Frequent measurements of large-scale transient phenomena.
- Water resources inventory and management.
- Determination of cause-and-effect relations among hydrologic phenomena.

Numerous experiments are planned on approved and planned flights in the NASA Program to develop space techniques which will be applicable for collecting hydrologic data. Hydrology is one of the disciplines included in NASA's Earth Resources Survey Program, and an active program is underway to develop sensors and techniques for obtaining hydrologic observations.

Following is a list of experiments being considered for flight on NASA spacecraft. The list includes only those experiments which pertain to hydrology.

***Advanced Technology Satellite ATS-1 (1966, Earth Synchronous Orbit)**

Instrumentation	Application
VHF Transponder	River gauge interrogation

*Launched December 1966.

***Advanced Technology Satellite ATS-C (1967, Earth Synchronous Orbit)**

Instrumentation	Application
Image Dissector Camera System	Snow cover
OPLE (Omega Position Location Equipment	Ground platform interrogation
Soumi Spin Scan Color Camera	Snow surveys, river basin outflow, pollutants

Nimbus B (1968)

Instrumentation	Application
Image Dissector Camera System	Snow surveys
IRLS (Interrogation, Recording and Location System)	Ground platform interrogation
Satellite Infrared Spectrometer	Temperature and water vapor profile

Advanced Technology Satellite ATS-D (1968, Earth Synchronous Orbit)

Instrumentation	Application
Image Orthicon Camera System	Snow surveys

TIROS M (1969)

Instrumentation	Application
Advanced Vidicon Camera System (AVCS)	Snow surveys
Automatic Picture Transmission (APT)	Snow surveys
Infrared Radiometer (HRIR)	Surface temperatures, snow surveys

Nimbus D (1970)

Instrumentation	Application
Satellite Infrared Spectrometer Filter Wedge Spectrometer	Temperature and Water Vapor profiles
Sferics Detector	Thunderstorm detection
Day/Night Radiometer	Temperature (surface and atmospheric)
IRLS (Interrogation, Recording and Location System)	Ground platform interrogation
Image Dissector Camera System	Snow survey
Cloud Top Radiometer	Cloud top height

*Launched November 1967.

Apollo Applications "AAP-A" (1970)

Instrumentation	Application
Day/Night Camera	Snow cover surveys
Dielectric Camera	Snow cover surveys
Multi-spectral Photography	Water surface roughness, rainfall distribution, snow surveys, river basin discharges, glacier monitoring, ground water discharge, lake and water reservoir monitoring.
IR Temperature Sounding	Temperature and Water Vapor profiles
IR Filter Wedge Spectrometer	
IR Interferometer Spectrometer	
IR Scanning Radiometer	
Multi-channel Radiometer	
Integrated Passive Microwave Experiment	Rainfall distribution, measurement of water surface roughness, ground water discharge and snow surveys, monitoring glaciers, lake and reservoir levels.
UHF Sferics Detection	Thunderstorm detection

2.6 OCEANOGRAPHY AND HYDROGRAPHY

2.6.1 Description of Scientific Field Considered

In ESSA's role as a provider of environmental services to the nation, the safety and well-being of our population is of prime concern. These needs have led to the oceanographic and hydrographic services of the Seismic Sea Wave Warning System in the Pacific (which warns against tsunamis), the various services for coastal and ocean navigation, tide analysis and prediction, storm surge prediction, and the forecasting of storms at sea. However, there are also obvious needs for more extensive environmental information and for more effective usage of our marine and coastal resources. Among the former is the need to provide oceanographic and hydrographic information on a global scale – information that will help man collect food from the sea, help him conduct commercial operations, warn of impending dangers, aid him by improving weather forecasts, and help him use the sea and its basins efficiently.

Oceanography is the science that deals with the study of the sea, incorporating all knowledge of the seas' physical boundaries, the chemistry and physics of sea water, and marine biology. The need to study the ocean as an integral part of the entire earth environment has been apparent for some time; at ESSA the ocean is treated as a correlated third in the earth's trinity of atmosphere, ocean, and land rather than as a completely separate entity. It is only in this manner that the objectives noted above can be attained.

Hydrography, as related to the oceans, has been concerned with the collection of hydrographic survey data and the depiction of water depths and sea floor configurations on a map base. This discipline is also undergoing a metamorphosis because of the prospects of man's continued penetration into the sea and his greater usage of the sea floor. More detailed knowledge of all aspects of the ocean depths, the currents, and bottom topography will be required on maps and charts, and methods have to be devised to present such three-dimensional information adequately – methods which do not exist now.

ESSA has incorporated these principles of oceanography and hydrography into its basic concepts for all present and future activity, with the realization that before new services can be developed or old ones improved, further understanding is required of the conditions of the sea floor, shorelines, and variable oceanic phenomena. In order to apply the available resources efficiently to these problems, three major research and operational areas have been created. These are:

- To chart and understand the continental shelves and ocean basins
- To chart, understand and predict physical oceanic processes, stressing the physical dynamics and variations in each ocean region
- To understand and predict oceanic environmental hazards and related conditions

Since these areas cross standard disciplines, the need for interdisciplinary cooperation is an absolute necessity.

The three major activities are described in the following sections.

2.6.1.1 Continental Shelf and Sea Floor Activity. The hydrographic charting effort is concerned with bathymetric/topographic descriptions. Although this program in the past has stressed and continues to emphasize surface navigation and its dangers, if we are to penetrate into the sea and use its resources efficiently, a new kind of map is required – one that will depict bottom topography and composition, water depths, and ocean currents. This information is needed to contribute to man's safety and work efficiency within the ocean environment so that he may develop its resources.

The Continental Shelf Mapping and Charting Program could lead to such a capability. The addition of political boundaries to continental shelf maps will include the establishment of state seaward boundaries on submerged land parallel to the shoreline (U.S. Congress, 1953) as well as the extention of state and national dry land boundaries into the sea. To locate such boundaries, and eventually property lines, to a suitable order of accuracy on the sea floor, techniques will have to be developed to extend geodetic control from dry land onto the sea floor and to establish sea floor control points to an adequate degree of precision. In addition, various requirements for new tools and methods have also been established to contribute to our understanding of the geology of the shelves and basins (configurations, structure, composition, and origin).

The application of remote sensing techniques from satellites to hydrographic charting will probably be confined to shallow water effects, such as the "doubtful shoal" problem. However, ESSA is considering the application of navigation satellites to locate the positions of ships as they station themselves over the 200 meter bathymetric contour, for the purpose of defining and locating the edge of the continental shelf to a better degree of reliability

than is normally practiced now in many parts of the world.

2.6.1.2 Physical Oceanic Processes. The study of physical oceanic processes encompasses physical oceanography, sea-air interaction, and land-sea interaction.

The program in physical oceanography is directed toward understanding the structure and dynamics of the oceans, including, for example, sea state, ocean currents, and ice and water masses. The need for a world-wide analysis and reporting technique of sea state is apparent, and improvements in the techniques are being developed as quickly as possible.

The plotting, prediction, and understanding of ocean currents on a monthly or seasonal basis will contribute to navigation, fishing, and scientific requirements. Observations of sea ice boundaries, structures, floes, and packs coupled with ice depth will contribute to the work of various agencies in predicting freeze and breakup of ice, to polar ice-cap climatology, to sea state prediction by defining fetch, to understanding associated sea surface circulation patterns, and to weather analysis. In addition, information on surface water masses will be a major input to sea-air interaction studies and weather prediction. The long-range goal is to develop a comprehensive knowledge of the seasonal, three-dimensional circulation patterns in each ocean basin. This knowledge is needed for the understanding and prediction of the heat budget and related climatic changes, the distribution of sea life, and the physical and chemical properties of the ocean. It is also believed that, before a detailed geodetic analysis of the sea surface and its relationship to the continents can be developed, it will be necessary to understand many aspects of the changing conditions of sea level, such as current slopes, ocean tides, and possible residual surface deformations.

Investigations of sea-air interactions are and will continue to contribute significantly to understanding and predicting meteorological and oceanographic weather and climatic changes. For this effort to be successful, information is needed on the micro-scale, mesoscale and macroscale relationships between these two massive, continuously variable environments. Therefore, a need exists for new tools and methods to collect information about the interaction parameters on a quasi-synoptic basis.

Land-sea interaction affects normal coastal processes, such as coastal currents, surf, storm surges, and estuary deposition and erosion, including small- and large-scale morphological changes. The prediction of tides has been a coastal problem; however, techniques are now being developed to obtain tide information over the open ocean.

2.6.1.3 Oceanic Environmental Hazards. Of special concern is the problem of predicting environmental hazards. In the fields of physical oceanography and hydrography such hazards include tsunamis, storm surges, high waves, and water pollution. Although long-range goals are directed toward environmental control, the present state of the technology limits services at this time to predictions and warnings that can be readily accepted by the public with confidence. As use of the seas and development of coastal areas increase, so does the need to detect and forecast high waves and storm surges on a global scale. Although it is a functioning service, the Seismic Sea Wave Warning System – a joint concern of the United States and other nations surrounding the Pacific – must be improved. There is also a growing requirement to detect and locate water pollution hazards, such as red tides and other dangerous chemical concentrations. The need to improve public warnings requires new methods and techniques to ensure that protective measures can be initiated promptly.

2.6.2 Proposals and Related Requirements

2.6.2.1 Scope. To improve ESSA's oceanographic and hydrographic services, an analysis was made of new methods, techniques, and tools to gather environmental data from space. The principles applied in this study and the criteria for the selection of priority experiments are discussed in Section 2.1. Table 2.6-A lists the oceanographic and hydrographic proposals of the panel. Starred items in the table are those selected as most advantageous and practical at this time.

It appears that for the first time in the history of oceanography a capability can be developed to collect quasi-synoptic global data on gross, surface oceanic features. With suitable analysis and display techniques, it will be possible to show the surface boundaries of major current systems over an entire ocean basin, the relative distribution of surface temperature over a large part of the world's oceans, the state of the sea and its wind field from continent to continent, and the polar ice caps and their water boundaries. Such regional displays, developed for proper time intervals, will contribute to the understanding of monthly, seasonal, and yearly variations of oceanic parameters. In addition, many surface phenomena of smaller size could also be

Table 2.6-A – List of Proposals for Oceanography and Hydrography

Proposal Number	Description	Special Orbit
*1#	Shoal water	
	"Doubtful and uncharted shoals" – danger to navigation	Polar or high inclination
*2	Sea State	Polar or high inclination
*3	Water masses – surface effects	Polar or high inclination
(a) #	Currents, ocean and coastal	
(b) #	Water composition hazards: such as redtides and dangerous pollution concentrations	
(c)	Estuary effluents	
(d)	Surface anomalies	
(e) #	Absolute sea surface temperature	
*4	Sea ice	Polar, synchronous
5	Beach and shoal water morphology	Polar or high inclination
6#	Coastal damage surveys	Polar or high inclination
7	Storm surges	Polar or high inclination
8	Sea level and sea slope	Polar or high inclination
(a)	Current slopes	
(b)	Ocean tides	
(c)	Variations of atmospheric pressure	
(d)	Residual deformation of sea surface	
9#	Tsunamis	Synchronous

#Requirements of major importance
*Proposals selected for detailed discussion

detected, for example, large eddies and current meanders, oceanic fronts, shoal waters, polluted areas, and sea ice patterns. The degree of detail to which oceanic phenomena could be observed by remote sensors from spacecraft will depend, primarily, on the development of instrumentation with adequate sensitivity and resolution.

In the proposals, the application of multiple electromagnetic sensors is stressed, each spectral waveband providing a special type of information for the same target area. Optical systems, such as cameras and spectrophotometers, can detect differences in water composition, particularly high contrast boundaries, because of variations in the penetration, absorption, and back-scatter of light in water. Infrared and microwave collecting systems (radiometers and image devices) measuring thermal differences of the ocean surface can detect currents, sea ice boundaries, and oceanic fronts. Active radar systems have been successfully employed over sea ice and varying degrees of sea state. Eventually, such systems will also provide useful data on the variations of sea level and storm surges.

Multiple sensors mounted in the same vehicle may reduce the problem of ambiguities which would be impossible to separate if the sensors are in separate vehicles. For example, visually transparent atmospheric layers trapping water vapor and aero-

Table 2.6-B — Proposed ESSA Spacecraft Experiments for Shoal Water, Sea State and Sea Ice — Part 1

Problem	Suggested Instruments	Resolution*		Wavelength	Recording	Environmental Data
		Meters	°C			
Shoal water	Cameras	30		Visible	Film, Color and B&W	Detection of shoals
	IR imaging system	200	0.5	10-11μ	Tape	Submerged bars, shallow sea-mounts (may be most useful in turbid water)
Sea State	Cameras	100		Visible	TV, Film	Sun glint and cloud patterns
	Radar Scatterometer	1,000		10-70 cm	Tape	Large area differentiation of sea state
Sea Ice	Cameras	30		Visible	Film	Boundaries, structures floes and packs
	IR imaging system	200	1.0	10-11μ	Tape	Boundaries, structures floes and packs
	Microwave imaging system	2,000	1.0		Tape	Boundaries
	Microwave radiometer	2,000	1.0		Tape	Ice depth

*The indicated resolutions are considered the minimum. Instruments that can improve these values are preferred.

sols, particularly downwind of industrial areas, have generated infrared emissions, producing signals in a radiometer, which have been confused with ocean surface thermal patterns (Oshiver, et. al., 1965). Multiple frequency systems could probably resolve this problem. Also, the Nimbus 2 high resolution infrared scanner (HRIR), which records on tape, combines the quantitative radiometer with the qualitative image function. With this instrument, thermal contours can be readily located on the corresponding image of the ocean area, easily avoiding the potential ambiguity of land and clouds.

The application of communication or interrogation satellites as related to buoys, ships, and other stations was not an integral part of this study, but it is considered as an equally important tool (see Section 2.6.2.7).

Table 2.6-B (Parts 1 and 2) lists details of the priority spacecraft experiments as they relate to ESSA's requirements for oceanographic and hydrographic data acquisition. The following sections discuss the individual proposals.

2.6.2.2 Shoal Water — A Hydrographic Problem. A world-wide problem is the detection and charting of doubtful and uncharted shoals. Since numerous offshore hazards to marine navigation are reported annually, these potential dangers must be shown on all pertinent nautical charts until either specifically disproved or properly identified by accepted survey methods. Such methods are not always practical because of high search costs. The problem was so acute that as early as 1947 member nations of the International Hydrographic Bureau (IHB) passed a

Table 2.6-B – Proposed ESSA Spacecraft Experiment for Water Masses – Surface Effects – Part 2

Problem	Suggested Instruments	Resolution*		Wavelength	Recording medium	Environmental data
		Meters	0°C			
Water masses – (Surface effects) (a) Currents, open ocean and coastal (b) Water composition hazards –Red Tides –Pollution concentrations (c) Surface anomalies –Plankton blooms –Sea weed –Underwater volcanic eruptions –Convection –Advection –Upwelling (d) Estuary effluents (e) Absolute sea surface temperature	Cameras	30		Visible and short wave infrared	Film, color and B&W	Thermal and composition boundaries – indicating shape and pattern differentiation
	IR imaging system	200	1.0	10-11μ	Tape	
	IR radiometer	1,200	1.0	10-11μ	Tape	Thermal contours
	Microwave radiometer	3,000	1.0		Tape	Thermal contours
	Microwave imaging system	2,000	1.0		Tape	Boundaries

*The indicated resolutions are considered the minimum. Instruments that can improve these values are preferred.

resolution (IHB, 1947) requesting that it be given top priority for immediate solution. It was estimated that by using only surface ships to investigate possible shoals, it would require 20 years of concerted effort by all member nations to resolve it. However, because of the need to rebuild oceanographic survey capabilities after World War II, it was not until 1965 that some member nations could accept responsibility for performing hydrographic surveys of certain parts of the oceans.

Since this problem encompasses all oceanic areas, a large area survey technique is needed to detect shoals and permit comparison of data obtained with existing hydrographic charts. Ships or aircraft could then be dispatched to specified locations for more detailed studies.

In addition to detecting shoal water close to land, information is needed about isolated shoals in the deep sea, and about partially or totally submerged stationary or floating objects (derelicts) which could be hazardous to ship operations. Image sensors which provide a coarse resolution could be used to detect most natural shoal features of vital interest, but resolutions should be better than 100 feet in order to detect bars and reefs. To satisfactorily identify "derelicts", remote image sensors should have very high resolutions.

The feasibility of using remote image sensors on spacecraft has been demonstrated for oceanic areas where waters are transparent. Figure 2.6-1 is an illustration of a hydrographic survey chart superimposed on a Gemini V photograph, which was exposed over Rongelap Atoll in the Marshall Islands – an area noted for its clear water. The photograph was exposed from a near-vertical orientation so that the imaged islands match the islands on the corresponding chart (SPOC, 1966); it is apparent that many of the charted reef lines do not coincide with the imaged coral reefs. This type of comparison technique could serve to identify charting problems in specific locations, and it could be used by survey ships as a guide for planning efficient resurveys.

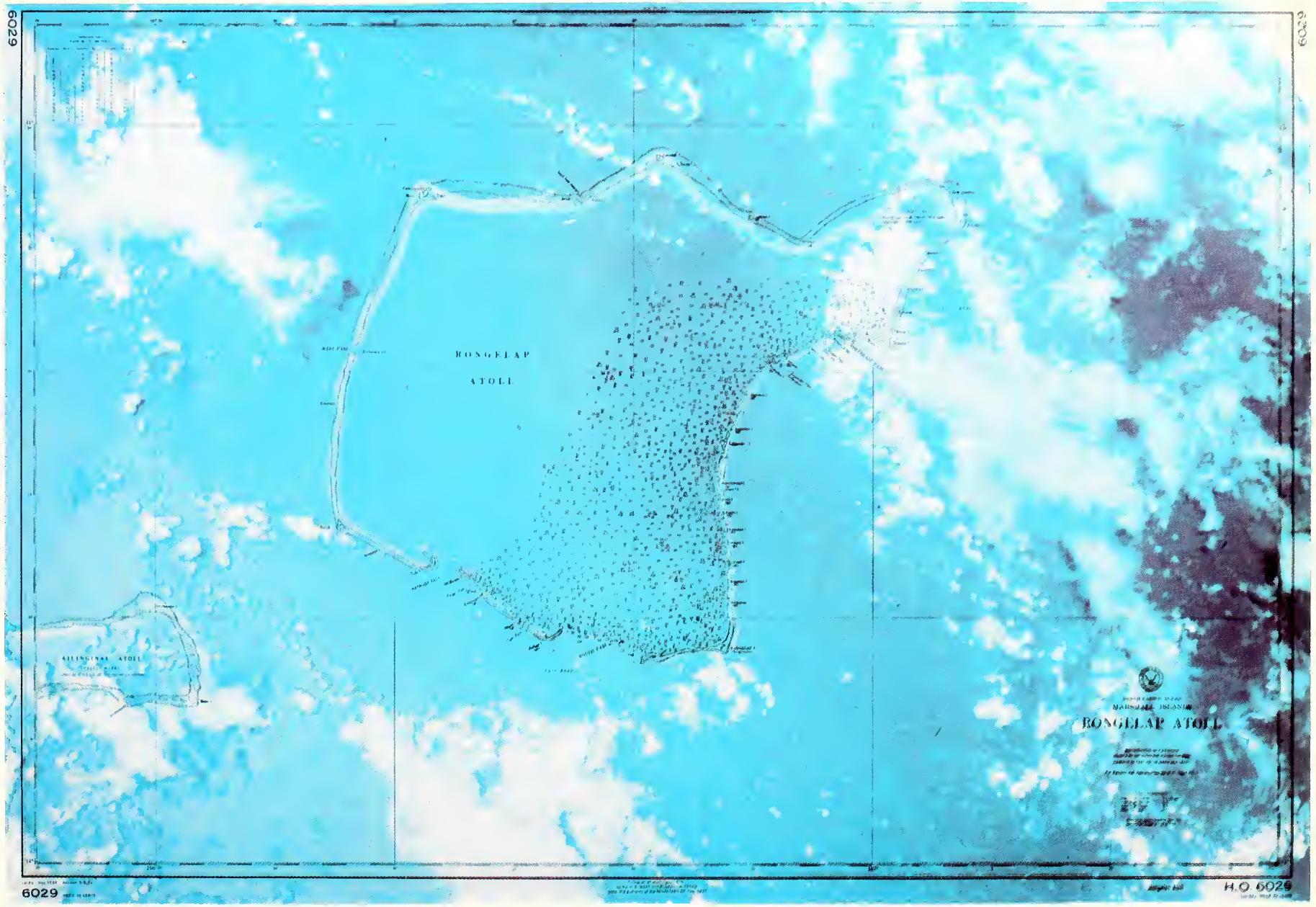

Figure 2.6–1. Gemini V photograph of Rongelap Atoll with a nautical chart overlay. (Photo: Astronauts L. G. Cooper, and C. Conrad, Jr. – NASA; Overlay, U. S. Naval Oceanographic Office.)

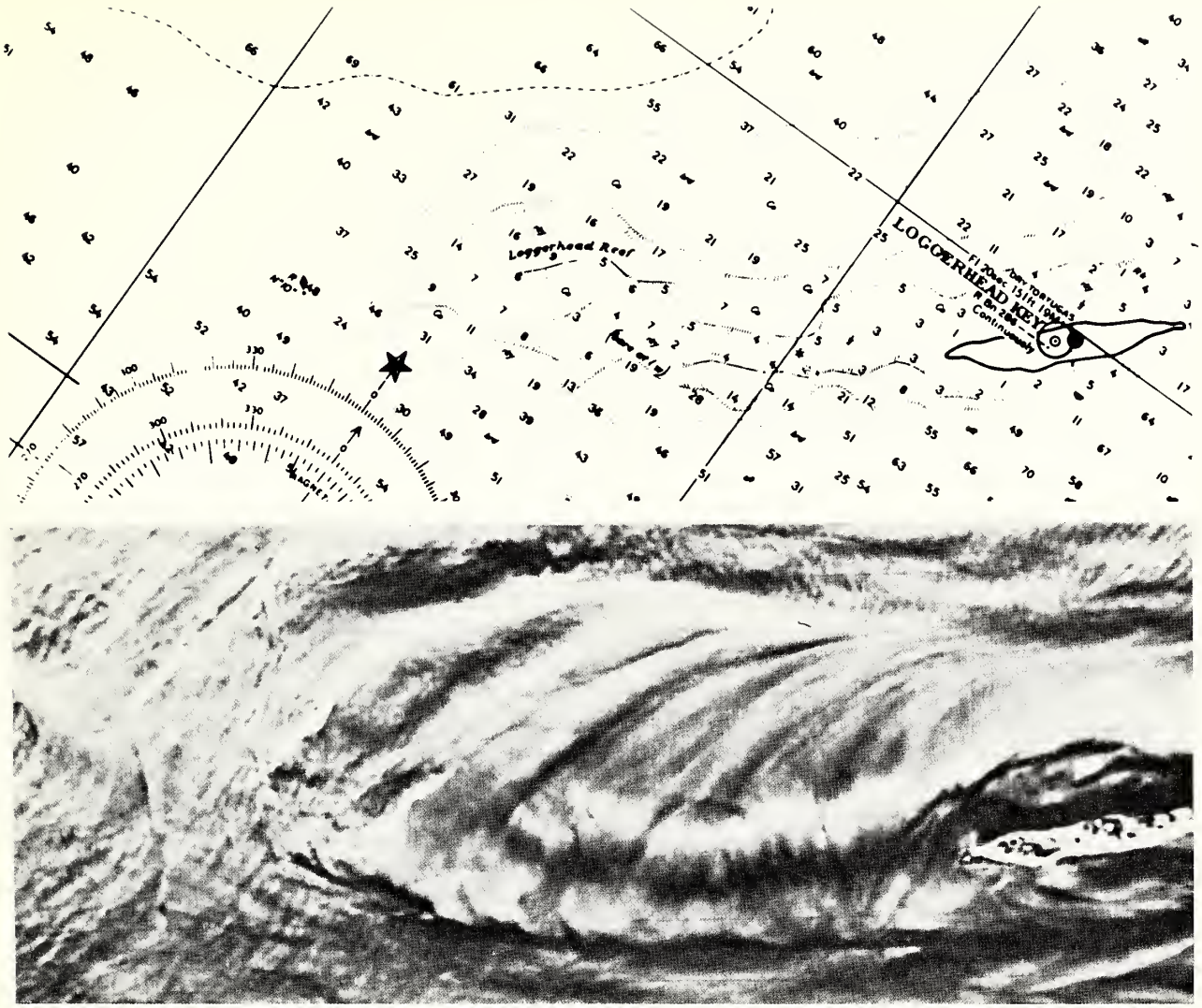

Figure 2.6-2. A chart and an infrared line scan photograph showing water movement over a bar. This system collects small differences in emitted infrared energy in the 8-14 micron wavelength band and translates it to a correlated glow tube which exposes b&w film to create the imagery illustrated above. Light colored areas are warm; dark are cold. (Photo courtesy U. S. Naval Air Development Center, Johnsville, Warminster, Pa.)

The accuracy provided by such photography is sufficient to correct horizontal positions on very small-scale charts, but it is not satisfactory to correct large-scale charts, or to determine depth. Since the advent of the Gemini photography, additional experiments and tests, such as the "Key West, Florida color photo test" – an interagency aircraft experiment, and the "Line Islands" satellite experiment, have incorporated techniques to further the potential capability of this promising method.

Where turbid oceanic waters restrict the penetration of light and prevent the use of normal photographic systems, infrared imaging systems, collecting variational infrared emissions from the water surface, could be used to detect hazardous shoals. Figure 2.6-2 shows an infrared line scan photograph exposed from an aircraft over a shallow water bar and a corresponding section of a Coast and Geodetic Survey chart. The image shows a striated structure caused by water movement over the submerged bar. The present state of the art does not permit comparable resolution from spacecraft, but a high resolution scanning system probably can be developed to detect large shoal areas and possible shallow seamounts from the observed effects of these features on ocean currents and temperature fields.

It will be necessary to cover all the world's oceans at least once to be sure all possible shoal areas have been detected. There will also be a need to monitor some oceanic areas at regular intervals

to detect relatively rapid morphological changes. This coverage could probably be provided best from polar-orbiting spacecraft.

2.6.2.3 Sea State. The state of the ocean surface, in terms of the condition of wave heights and patterns, is now predicted using wind information as input into a mathematically generated sea surface model. Predictions are made for North Atlantic and North Pacific shipping lanes and adjacent oceanic regions. The actual measurement of wave heights is confined almost exclusively to the random utilization of wave recorders on ships or buoys. Measurements by airborne systems, such as stereo photography and radar and laser altimeter wave-profile recorders, although successful, provided only limited areal coverage.

A method is needed to depict synoptic sea and swell characteristics over vast oceanic expanses. Such a method would facilitate global forecasting of wave patterns and associated wind fields. Although a spacecraft system of this capability is not yet available, an experimental radar scatterometer technique (Pierson, Tick, and Baer, 1966) has been developed that could detect gross characteristics of the sea surface and that would permit sea state forecasting by wave height zones, such as large concentric bands generated from a storm center. The application of such a system to spacecraft is considered feasible. It would be designed to compare return signals collected at various zenith angles from the same section of water (see Section 2.4.2.4). The differences in the return signals provide an indication of sea surface roughness, and the relation between surface roughness and wind is expected to provide information on surface winds.

Although a great deal of development work will be required, including aircraft experimentation over various sea states and intersecting wave train combinations, this method is attractive because the radar wavelength would be long enough to penetrate most clouds. In addition, the data requirements per profile are very modest, compared to a tape stored image system, and could be read out at frequent intervals for automatic insertion into a computer, generating wave analyses quickly. Because of global coverage, preferably from polar orbit, an understanding of quasi-synoptic sea state and associated winds could be obtained for each ocean basin, providing knowledge never before attained in the history of oceanography.

Research into other methods is also progressing – notably in multispectral microwave radiometry. However, a great deal of work is needed to understand the basic physics of ocean surface phenomena as correlated with microwave emission.

Imagery from the TIROS and ESSA series are being used now at the National Environmental Satellite Center to examine sun glint effects to determine sea state. It is apparent that as sea state increases, the sun's image on the photograph develops a halo effect due to specular reflections off the sides of the waves. This halo tends to increase in size with increase in sea state; however, no absolute correlation of dimension with sea state has been possible as yet, due to insufficient oceanic data at the times and places corresponding to the imagery. In addition, the correlation of low altitude cloud patterns with surface winds also suffers from insufficient oceanic data, but it appears that the techniques are worthy of further investigation.

2.6.2.4 Differentiation of Water Masses (Surface Effects). When considering the earth's three-dimensional liquid envelope – the ocean – investigators have found that it undergoes seasonal changes and alterations that take place in somewhat the same manner, though less rapidly, as the earth's gas envelope – the atmosphere. Although we have a fair concept of ocean basin circulation, at least in gross terms, seasonal and local changes in three dimensions are still comparatively unknown. These changes create variations in ocean surface patterns which are modified by interactions with the atmosphere. For example, currents change in position and develop meanders of varying size and direction; warm and cold eddies, large and small, separate from currents at unknown time periods and locations; interchanges between currents, such as the Labrador and Gulf Stream, vary seasonally in intensity and location. Upwelling occurs regularly at certain places, intermittently at others, while sinking is associated with various features, including the Antarctic Convergence Zone. It is also known that plankton and Antarctic krill, near and at the ocean surface, collect in amorphous clouds; little is known however, of their size, depth, or distribution.

It is believed that if the variable surface water configurations could be detected and plotted regularly, the charts could aid the surface navigator, help the fisherman, and serve as the initial locating element for additional data collection of three-dimensional information. Information of this kind is needed for a further understanding of the ocean basins, and all the oceanic sciences could use it now.

The identification of the surface effects of water masses is divided into five categories: A. currents – open ocean and coastal, B. estuary effluents, C.

surface anomalies, D. water composition hazards and E. sea surface temperature. To differentiate these surface effects, the oceanic parameters of water temperature, composition, and movement will be exploited to the fullest possible degree, and a group of electromagnetic frequency systems, both radiometers and imagers, have been proposed for initial spacecraft experiments (see Table 2.6-B, Part 2).

Differences in temperature can be detected by infrared and microwave emissions. Infrared radiometers and imagers working in the various "atmospheric water vapor windows" appear to be the most promising at this time for the detection of thermal

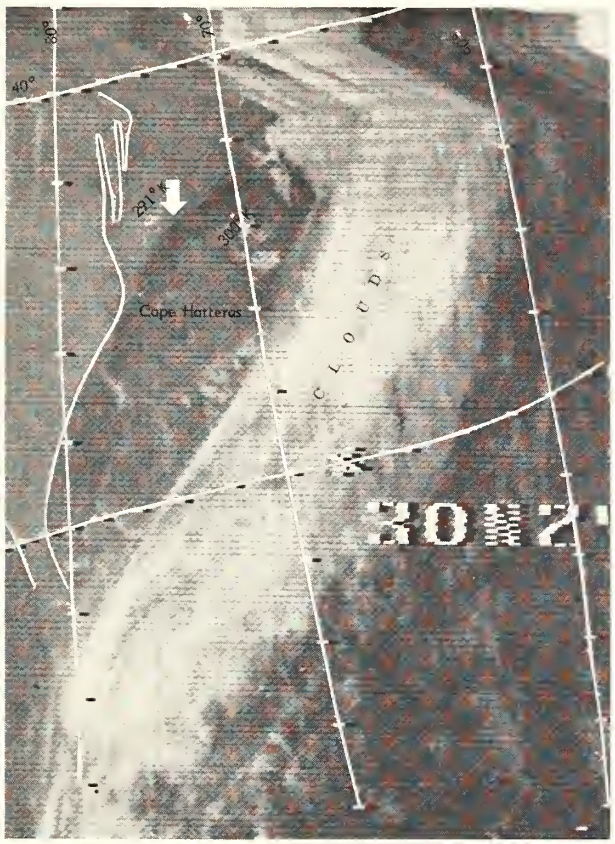

Figure 2.6-3. Nimbus II HRIR photograph of the U.S. east coast and Gulf Stream. Data orbit 238. Date: 2 June 1966. Time: 050100Z (local midnight time). White arrow points to boundary of Gulf Stream with coastal water. Temperature in degrees K on both sides of the boundary were determined from low altitude aircraft infrared radiometer readings collected at the same time as the spacecraft observation. Nimbus II HRIR is a line scan single channel recorder; 268 spots per second on tape read out to ground stations where the imagery is created. Lead selenide detector, spectral range 3.4-4.2 microns; radiation cooled down to -75°C. Geometric resolution is 8 mr; at 1100 km altitude, ground resolution is 8 km with thermal resolution of 1°C. Dark tone areas are warm; light are cold — such as the tops of the clouds.

patterns on the ocean surface. This fact has been confirmed by the Nimbus Medium Resolution Infrared (MRIR) multispectral system (see also Section 2.4.2.3) and the Nimbus High Resolution Infrared (HRIR) (Figures 2.6-3 and 2.6-4). It is expected that such systems will be correlated with other spectral absorption band devices designed to detect variations in atmospheric composition.

Microwave systems are in the early stages of being used in aircraft for the detection of oceanic phenomena. It is apparent, however, that both radiometers and imagers could detect high contrast, large area, thermal boundaries in ocean water, at least qualitatively. In addition, the potential capability of microwave radiation to penetrate clouds indicates a possibility for overcoming a very difficult problem.

Camera systems can also be used to detect water masses, exploiting oceanic parameters related to differences in water composition. Ocean water is a complex mixture of solubles, colloids, suspensoids, and biologic matter, such as algae, plankton, and seaweed. Visible light is absorbed, scattered, and reflected from below the surface in different spectral bands and in varying amounts (DuPre and Dawson, 1961). These differences create variations in color, brightness, and contrast boundaries on the film, and the image variations are the clues by which oceanic masses can be distinguished. Camera systems will function best, using color or black and white film, where there are major boundary differences in the water mixtures creating high contrast effects.

The use of spectrophotometers may eventually prove useful for developing water composition signatures since they collect data in a quantitative form. However, there are so many potential variables in ocean water mixtures that a long period of data collection and analysis may be required to fully understand the signature problem. At this time, spectrophotometers have been used primarily with cameras to arrive at the best film/filter combination for ocean surface imagery.

Each of the water surface categories is discussed in more detail in the following sections.

A. Currents

Information about ocean currents is utilized in the routing of ships. The cruising speed of most old freighters is about eight knots. If they leave a U.S. northeast coast port and head south to the Gulf of Mexico or Central America, the captains try to avoid the north-flowing Gulf Stream, which varies in speed from 2-5 knots. If they head into the

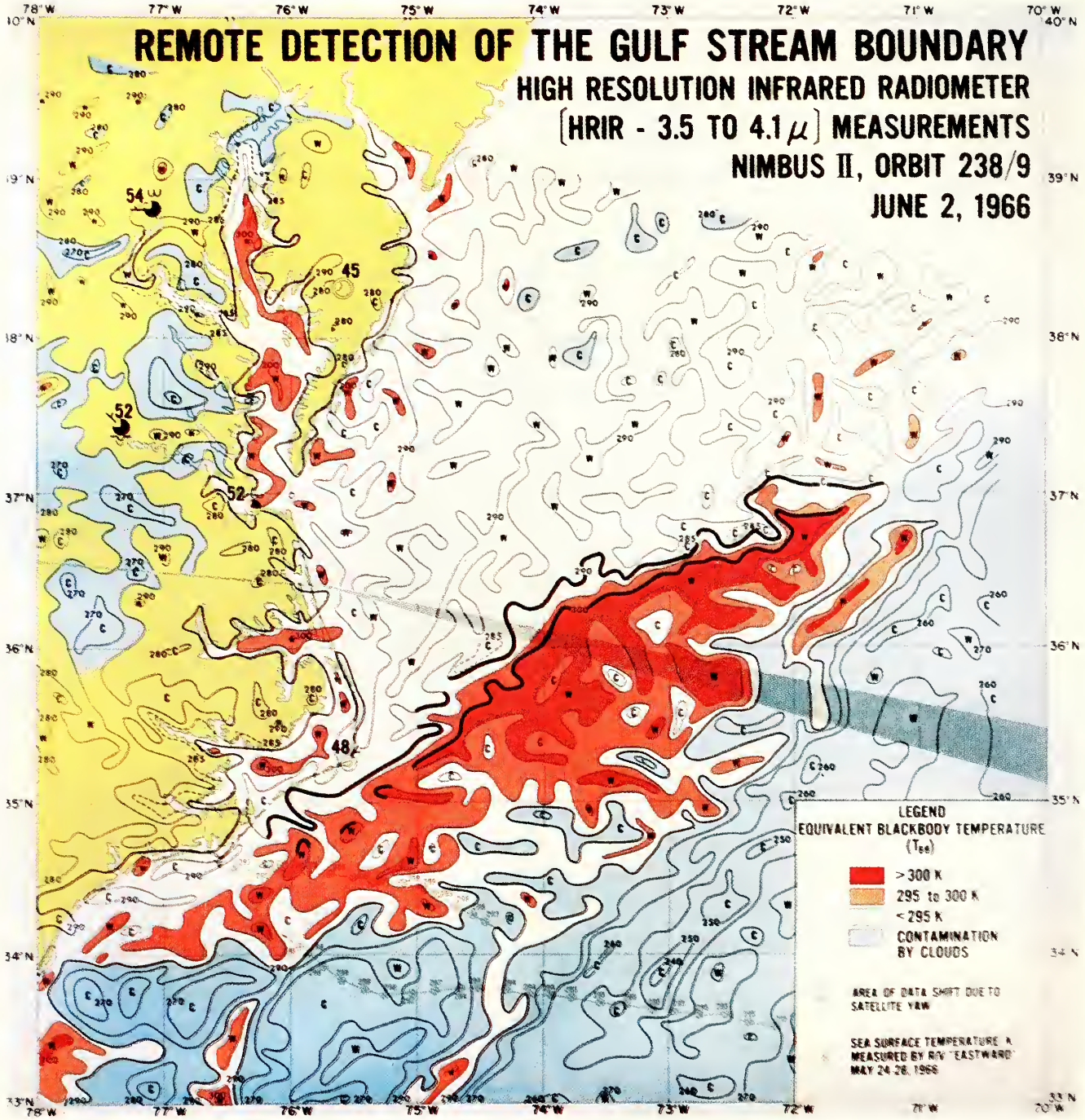

Figure 2.6-4. Nimbus II High Resolution Infrared Chart of the Gulf Stream Surfaces Temperatures on June 2, 1966. (Warnecke, Allison, Foshee, and Wilkerson, 1967).

Stream, they lose from 25-60 percent of their forward speed; therefore, slow freighters tend to hug Cape Hatteras, dangerous Diamond Shoals, and the shoal water near the Keys because of the close proximity of the Stream. Such activity increases either the hazards of piloting slow ships near shoals, or it adds travel time, which means excess cost. Even faster moving ships, traveling 15-20 knots, try to avoid unfavorable currents because, in the highly competitive world of sea transport, every effort is made to reduce costs. Up-to-date current maps could help the navigator plot his course for maximum safety and minimum cost.

Current information is also used in the fishing industry, where changes in temperature, salinity, and nutrient levels affect the habitats of fish. For example, the movement of relatively warm Gulf Stream water onto the banks off New England and Nova Scotia is known to drive away coldwater fish of commercial value. If the fisherman had advance warning, they could route their vessels to suitable areas or stay in port, rather than lose money on a wasted trip.

Charting currents from space on a global and quasi-synoptic basis will, of course, provide an important input to sea-air interaction studies, long-range weather prediction, and heat budget and climate research. Global information of this type will also allow the oceanographer to send out ships and instrumented aircraft to monitor an area in greater detail and to place buoys in arrays leading to more significant knowledge than is now possible.

Figure 2.6-3 is a reproduction of a Nimbus 2 HRIR image exposed off the Atlantic coast of the United States. The white arrow on the photograph points to a contrast line that is believed to be the northwestern boundary of the Gulf Stream. A microdensitometer trace across the contrast line of the photograph indicated a relative temperature difference of 9 degrees. The same difference was obtained by an infrared radiometer during a simultaneous low altitude aircraft flight. The position of the contrast line also corresponds to the known western boundary of the Gulf Stream as determined from surface observations at the time of the spacecraft passage. From this system, sea surface thermal isolines showing relative temperature differences for any direction across the image can also be extracted from night photography, Figure 2.6-4 (Warnecke, et. al., 1967). By locating the contours of the image, the potential ambiguity of clouds and land can be easily avoided. Microwave image systems could be used in the same manner as the Nimbus HRIR with the possibility of providing much of the needed information under some cloud conditions.

Photographic systems may also provide a capability for detecting current boundaries (Barnett, 1966). In the open ocean, however, most of the light reflected from below the surface is blue to green, and the differences in water composition are smaller than along the coast-lines. In addition, variable sun angles over an ocean basin will result in varying amounts of light back-scattered from the sea. Also, radiation losses due to the atmosphere will further reduce photographic contrast.

Therefore, the photographic systems must be extremely sensitive to small variations of available light, primarily in the blue spectrum, and every effort should be made to enhance the contrast effects during collection and processing. Color film is recommended for this purpose because small variations of color contrast are more easily detectable by the normal human eye than small changes in shades of gray. Another possibility is a multiband camera (Molineux, 1965) which is designed to collect, simultaneously, multiple photographs of the same scene in different spectral bands, each photograph being exposed through a separate, narrow, band pass filter. With this system, each waveband can be designed separately for maximum performance, and the imagery can be superimposed during processing into a color rendition of the sea surface. Since the purpose is to detect information easily, false color combinations have been used successfully where small variations in tone have been rendered in readily observable high contrast colors.

A photographic system for oceanographic purposes on board an environmental spacecraft may be combined with that required for other disciplines (see Section 2.9 and Figure 2.9-4).

B. Estuary Effluents

There is a need to determine the displacement patterns and boundaries of estuary effluents where major river systems empty into the ocean. This type of data, acquired at suitable time intervals, will provide information about seasonal changes in coastal processes that affect beaches and other coastal features. The sensors proposed for ocean currents can also be applied to detect the thermal and water-

composition boundaries of effluents. Figure 2.6-5, an infrared line-scan image exposed from an aircraft shows the teardrop-shaped displacement plume of the efflux from a New Jersey reservoir emptying into the Atlantic Ocean.

C. Surface Anomalies

Surface anomalies, such as eddies, fronts, upwelling, thermal and composition changes associated with underwater volcanic eruptions, plankton blooms and large areas of sea-weed, are natural features caused by dynamic processes and environmental conditions in the ocean. The detection and display of such anomalies will contribute to the understanding of the dynamic variables.

The surveillance of large areas of floating sea-weed could provide a key to long term ocean basin circulation cycles. It has been theorized, for example, that specific circulation features are responsible for trapping the sea-weed in the Sargasso Sea and in certain areas of the Pacific. It is desirable, therefore, to monitor such areas extensively.

Infrared, microwave, and photographic systems discussed in section A (above) could be applied, but an additional tool may be useful. Some of the upper surface layers of floating sea-weed is often dry, and since dry broadleaf vegetation with little or no surface water on the leaf is highly reflective in the near infrared, the use of infrared color film is also recommended. This film is designed to present infrared energy as visible red on the photograph, red energy as visible green, and green energy as visible blue. The system is normally used with a "minus-blue" filter, suppressing the blue energy returns from the water. Therefore, photography collected during periods of low sea state should present a high contrast rendition of bright red for the surface layer of the sea-weed and a blue-green for the water.

The ocean surface variables of eddies, meanders, loops, fronts, and upwelling are generally associated with differential movement. To understand these current interfaces, the variable boundary conditions should be observed at frequent time intervals.

Infrared line-scan image and photographic systems have successfully detected eddies and fronts from aircraft. For example, Figure 2.6-6, an infrared line-scan image, shows an ocean eddy about 4 miles in diameter approximately 200 miles east of Cape Cod. Figure 2.6-7 is another infrared line-scan image exposed in the same vicinity showing an oceanic front. Figure 2.6-8 (Smith, 1963) is a color photograph taken from an aircraft. It also depicts an eddy, approximately one mile in diameter, in the

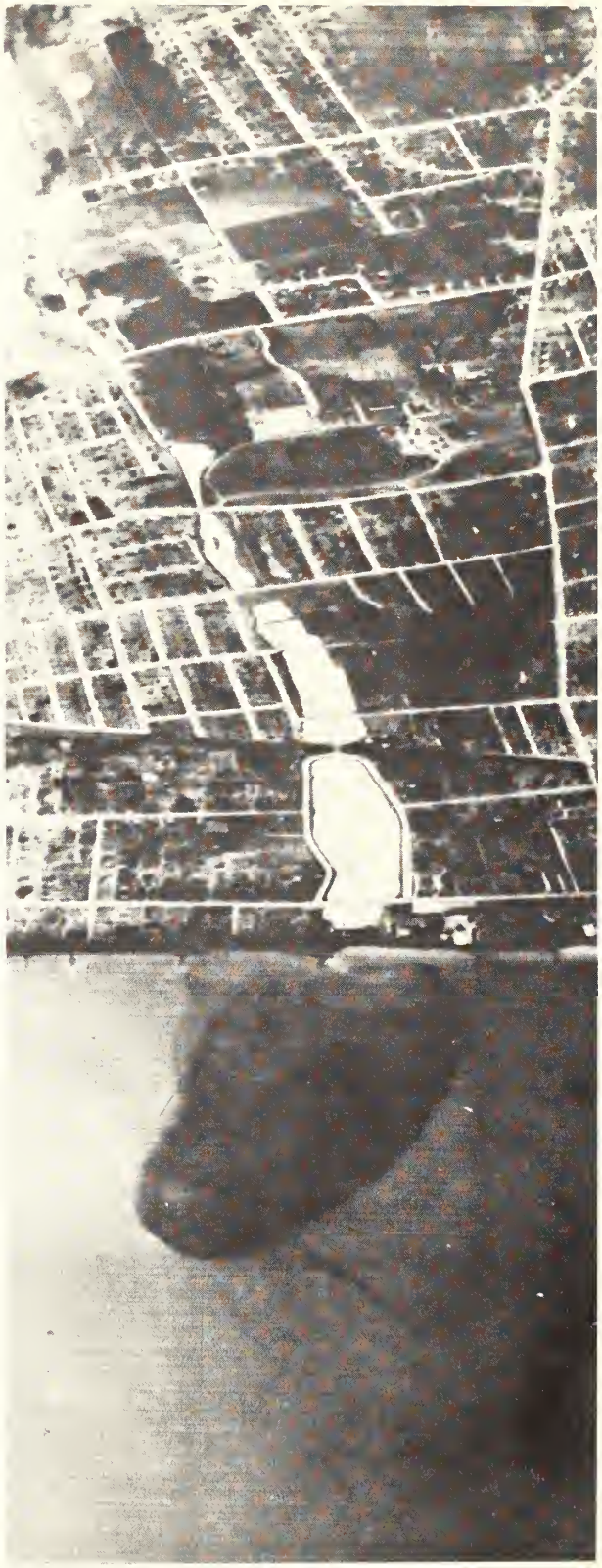

Figure 2.6-5. Infrared line scan photograph showing the displacement pattern of a New Jersey reservoir emptying into the Atlantic Ocean. Dark tones represent cool water, light tones, warmer water. Spectral range, 3-9 microns. (Photo courtesy U. S. Naval Air Development Center, Johnsville, Warminster, Pa.)

Caribbean Sea north of St. John in the Virgin Islands. The differences in tone are probably caused by small differences in light absorption and back scatter along the current boundaries. Repeated coverage at 15-20 minute intervals, for both Figure 2.6-6 and Figure 2.6-8, could possibly detect eddy movement, assuming structural shapes are maintained.

It may be possible to detect underwater volcanic eruptions, but the probability of doing so may depend on continuous monitoring of suspected areas, such as over known volcanic zones after an earthquake. Thermal and water discoloration anomalies due to changes in heat flow and chemical composition may be detected by infrared line-scan image systems and color and spectral zone cameras. Exuded gases, such as sulfur dioxide, may also be detected by sensitive, absorption spectroscopic systems.

These examples indicate the potential feasibility of detecting interesting oceanic phenomena from spacecraft, assuming the thermal and spectral sensitivities as well as the spatial resolutions are adequate.

As a by-product, these data will be of value to other groups such as those interested in oceanic

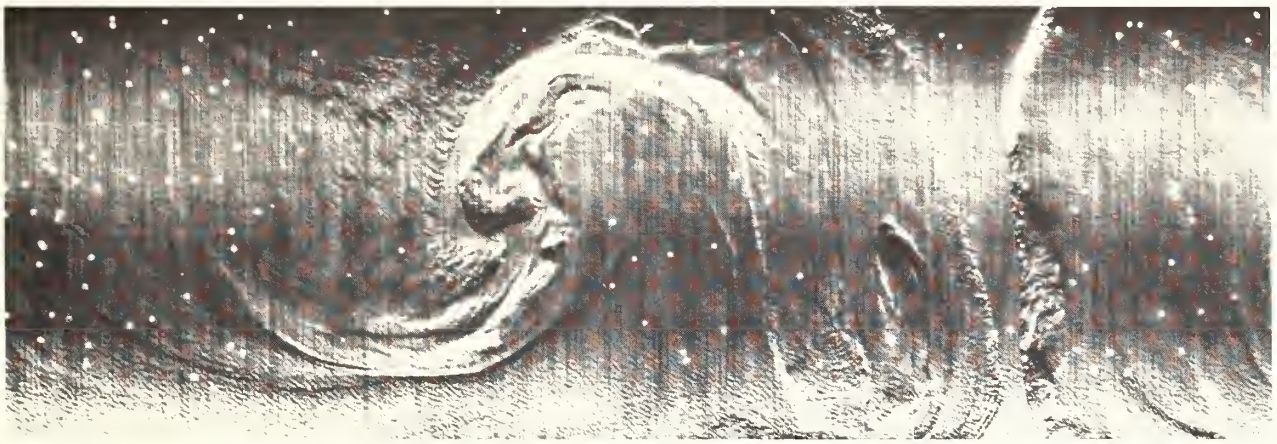

Figure 2.6-6. Infrared line scan photograph of an eddy approximately 200 miles east of Cape Cod. Date: 26 April 1963. Time: 2225R (Night). Coordinates 41°48'N, 64°40'W. Spectral sensitivity 8-14 microns. Length of area shown is 11 nautical miles. The white spots indicate electronic malfunction in the scanner. Light tones are warmer than dark tones. The intensity of tone contrasts can vary with the gain setting in the instrument. (Photo courtesy U. S. Naval Air Development Center, Johnsville, Warminster, Pa.)

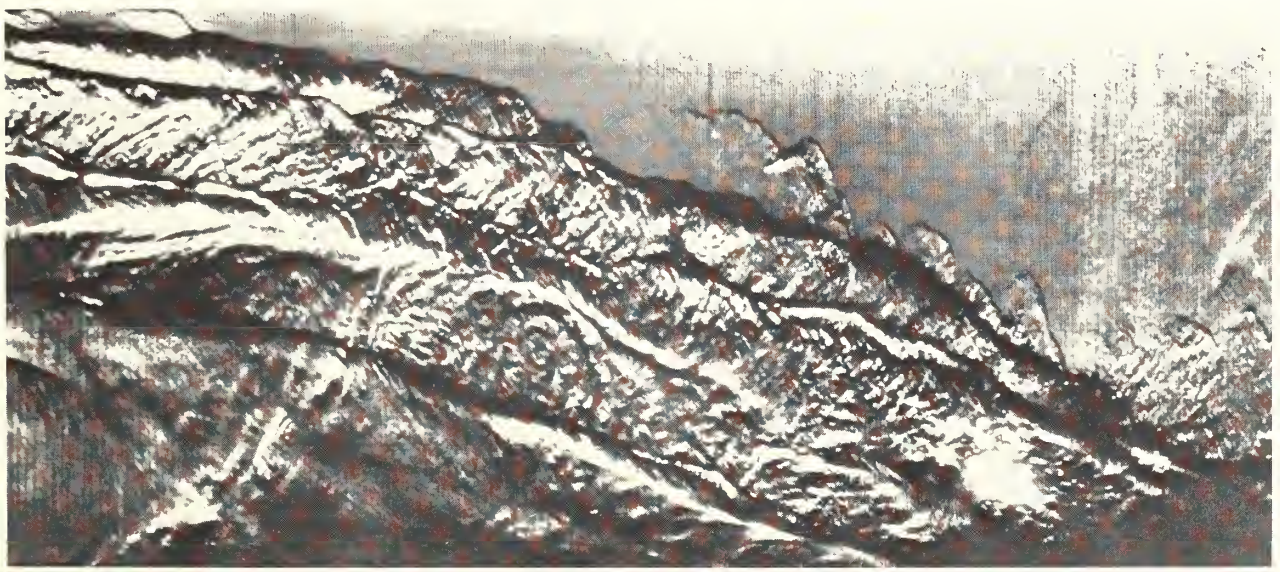

Figure 2.6-7. Infrared line scan photograph showing an oceanic front. Date: 26 April 1963. Time: 2151R (Night). Coordinates: 41°23'N, 64°28'W. Spectral sensitivity 8-14 microns. Length of area shown is 7.8 nautical miles. Light areas are warmer than dark tones. The intensity of tone contrasts can vary with the gain setting in the instrument. (Photo courtesy U. S. Naval Air Development Center, Johnsville, Warminster, Pa.)

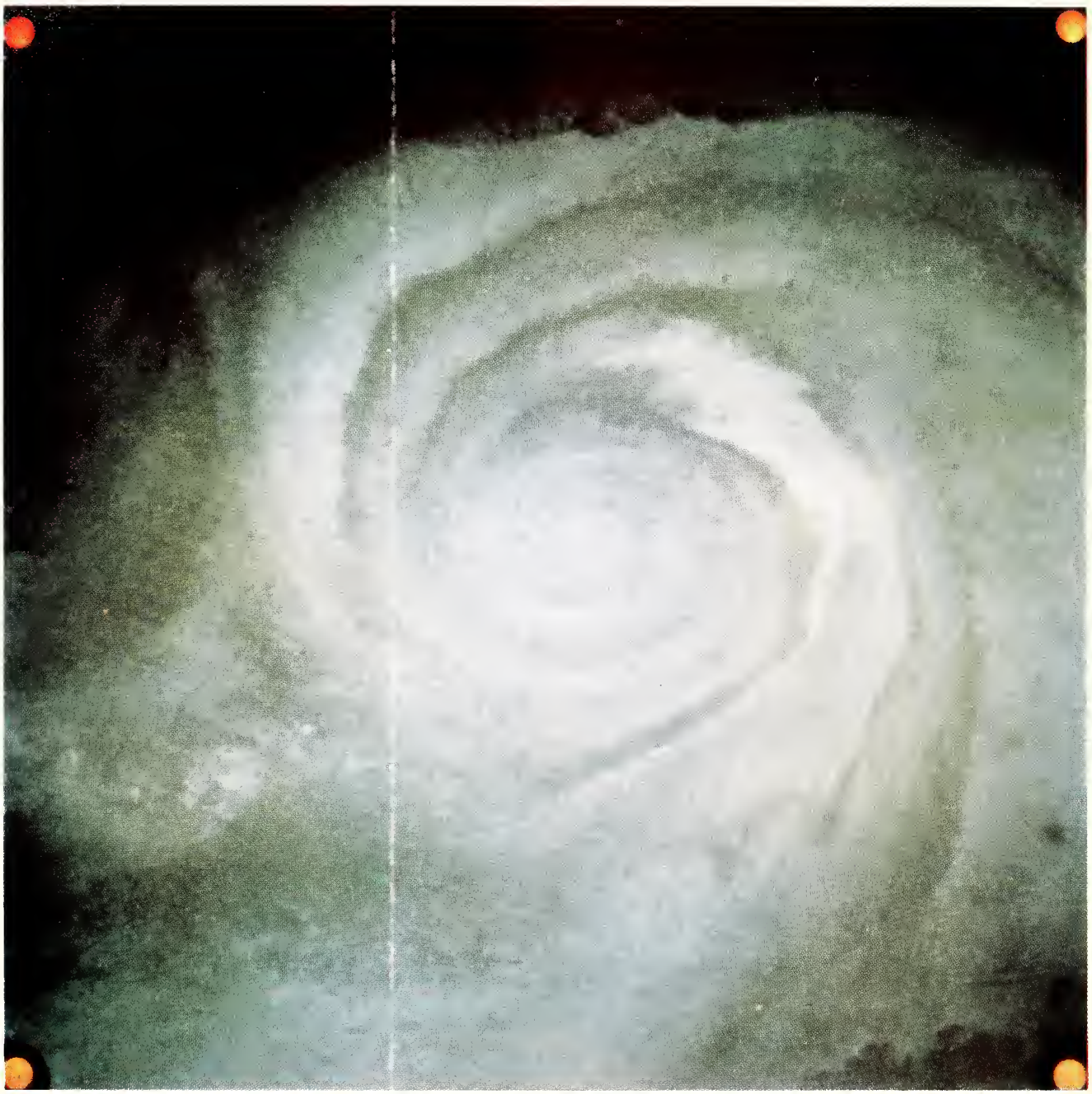

Figure 2.6-8. The color photograph shows an eddy, approximately 1 mile in diameter, in the Caribbean Sea north of St. John in the Virgin Islands, Camera: WILD RC-8, 9" x 9" format. Focal length: 152.29mm. Flight altitude: 5,000 ft. Note: Due to several stages in the reproduction, color tones and contrast effects have been altered from the original. (Photo: John Smith — Coast and Geodetic Survey, ESSA).

food source cycles and fish migration factors. Such knowledge, for example, could help the marine biologist decide where and when to place guides and traps for the coming fish farming industry, aid the deep sea commercial fisherman in his search for tuna, and contribute to the sport fisherman's search for big game fish. Photographic systems using natural or artificial color may be capable of detecting plankton blooms and Antarctic Krill, but because of low contrast conditions expected at spacecraft altitudes, spectral zone camera systems may be more practical.

D. Water Composition Hazards

A global capability for detecting water composition hazards, such as red tides* and other dangerous pollution concentrations, is needed. Although areas of red tide activity close to the United States, such as those off San Diego, the west coast of Florida, and Jamaica Harbor, are under continuous surveillance, image sensors are needed that could delineate the boundaries and specific locations in other areas of the world as quickly as possible. Because of its distinctive color, a red tide should be easily detected by color photography, a spectral zone image system, or a spectrophotometer. Methods are also needed to detect other kinds of pollution concentrations by remote sensors and should be able to discriminate kind, as well as locations and boundaries.

E. Absolute Sea Surface Temperature

Oceanographers and meteorologists agree that quasi-synoptic measurements of absolute sea surface temperature, obtained at frequent intervals, are needed for all the world oceans. This information is required for earth heat budget analysis, weather and climate prediction, and the fishing industry. In addition, a study of quasi-synoptic sea surface temperature distributions over an entire ocean basin for various time intervals may reveal undisclosed surface circulation patterns.

As pointed out in Section 2.4.2.3, the prospects of obtaining 1°C to 2°C accuracy from spacecraft now appear feasible. If the system were oriented vertically in a polar orbiting spacecraft, quasi-synoptic horizontal thermal profiles for each ocean basin could be prepared, preferably by automatic processing techniques.

The correlation of such information with temperatures obtained by ships and buoys interrogated from satellites, such as proposed for the World Weather Watch, would provide an independent sensor check. Such comparisons would not only lead to the development of better correction techniques for the spacecraft data but also supply some additional information on the intervening atmosphere.

Since this system is infrared, it is limited to the the collection of data where there are no intervening clouds. Advances in microwave techniques will be required to overcome the cloud problem.

2.6.2.5 Sea Ice (and Related Observations). The economic growth and development of many nations, especially in the northern hemisphere, have been very closely associated with the development of their maritime capabilities – the ability to transport goods, raw material, and personnel by ship. Many nations are faced with the problem of operating their maritime forces during periods when ice chokes inland lakes, waterways, seaports or normal sea routes. When this occurs, more expensive modes of transportation must be used to move material inland from ice-free ports, or over or around ice-covered waterways. Ships may stand idle in ports for several days or weeks, waiting to load or unload cargoes. Shippers and other maritime interests need to know – in advance – what ports will be open, and when, and what ice conditions exist or are expected to exist enroute. Knowledge of existing and forecasted ice conditions influence many decisions, such as when and where to employ icebreakers, when to dispatch individual ships or convoys for Arctic or Antarctic resupply, and the most expedient routes to use with the least amount of time underway or exposure to danger to life and property.

Scientific concern with ice varies according to the discipline involved. Yet each discipline, in its own way, contributes to a better knowledge and understanding of how and why ice behaves as it does, thus providing a basis for improved methods of predicting changes in one of the most fundamental of environmental phenomena. The meteorologist is concerned with ice primarily as an indicator or reflector of climatic changes. The hydrologist is con-

*Red tide – caused by a sudden, rapid reproduction and concentration of certain species of zooplankton in sea water. A "bloom" effect results, producing a distinctive red hue which has been known to cover hundreds of square miles. These plankton produce toxants which can cause mass kills of fish and other marine animals. Toxic particles from red tide areas and associated beach trash become airborne and are often carried inland, where they produce irritating effects in the mucous membranes of the eyes and respiratory systems of people and animals.

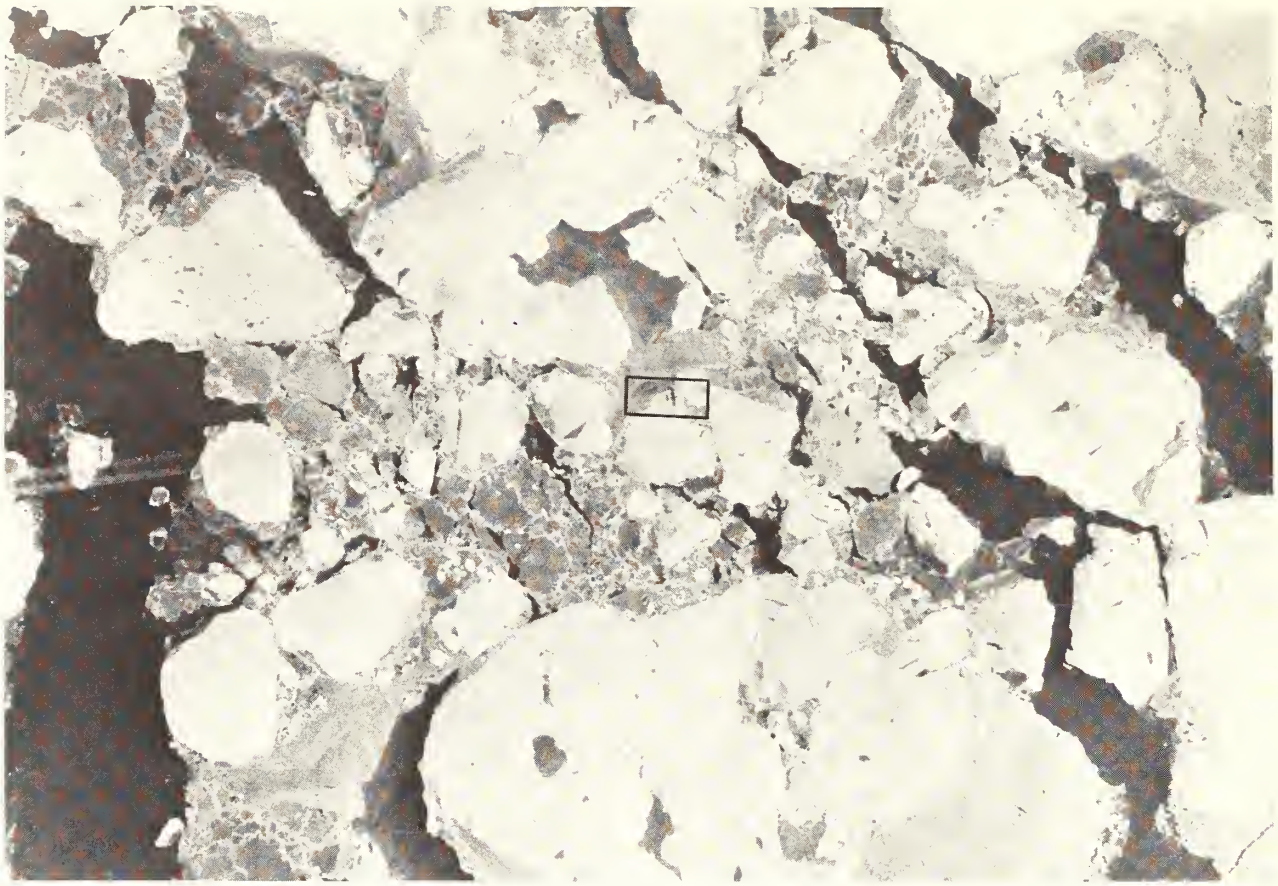

Figure 2.6-9. An aerial photograph of ice in the Gulf of St. Lawrence, February 1962. This photograph, taken from 41,000 feet, illustrates a few of the many variations in ice size and tonal characteristics typically observed in ice-infested waters. Tonal variations are indicative of ice thickness, age, and stage of formation or break-up. This, together with size, helps determine ice "traffic-ability." Practical satellite applications to ice reconnaissance require sensors capable of providing information on ice size and tone. (The block near the picture center is another photo aircraft at 18,000 feet). (Photo courtesy RCAF).

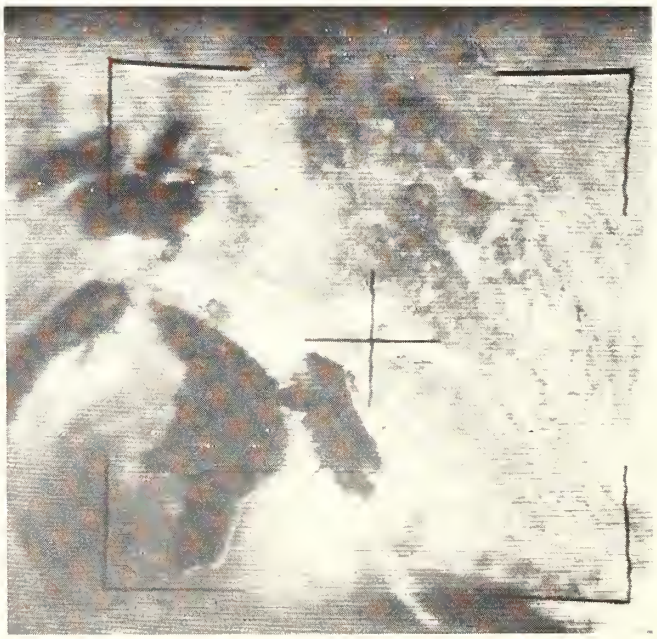

Figure 2.6-10. A TIROS VII photograph taken over the Great Lakes area on February 5, 1964. The largest, most prominent lake visible here is Lake Huron (lower left); Superior, Michigan, Erie, and Georgia Bay are also visible. The thin ribbon of white along the southern and southeastern shore of Lake Huron is "fast ice," attached to the shore, beached or stranded in shoal water. Photographs such as this help "tie in" spot reports of ice conditions along coastal areas, aiding ice forecasters and ship routing officers predict ice conditions affecting transportation or recreational activities.

cerned with storage of water in the form of ice in lakes, rivers and reservoirs, its formation and rate of melt, and the presence of ice jams or other features which might produce flooding. The oceanographer, perhaps more than the other two, is most concerned with the effects of ice as a hazard to shipping, as an indicator of ocean currents, or as it affects marine food resources. The concern of the meteorologists and hydrologists with ice is discussed under Sections 2.4 and 2.5, respectively. Here we are concerned primarily with the oceanographer's interests.

In areas where sea ice is transient, existing only during a certain time of the year, its presence provides an opportunity for photographically tracing currents, mapping their existence, direction, and velocity. This knowledge can then be applied during ice-free periods for more effective ship routing. It also provides an opportunity for studying marine life associated with these currents. In areas of more permanent ice, large water openings are known to occur even during periods of prolonged subfreezing temperatures.

The primary vehicle for obtaining ice information today is the aircraft. Aerial ice reconnaissance aircraft are used to search for leads or openings in the ice large enough and long enough for ships to get through. In addition, the aerial ice observer looks for certain features which indicate ice formation, advance, or break-up, or characteristics which show that icebreakers could be used to open ice covered ports or waterways for shipping.

Canada recently spent $5,000,000 to instrument two aircraft specifically for ice reconnaissance. Many aircraft are employed for ice reconnaissance missions, both over the oceans and in the Great Lakes region. Ship and land station reports complement the aerial reconnaissance program. Information from these sources is sent to major ice centrals or other collection centers for use in forecasting.

Reconnaissance flights provide information on many ice features. For long-range ice prediction (30 days or more) the forecaster is primarily interested in the location of sea ice boundaries (±10 n.m.), concentration (percentage of ice cover within a given boundary), and depth (in inches). For short-range forecasts of 5 days or less, and for close tactical support of ship operations, additional information is needed: ice type (ranging from slush to large ice fields), age (new or young, medium, or winter), topography (presence of ridges or hummocks several inches or feet in height), presence of cracks or other small open water leads, and other features. When studying ice conditions in bays or off-shore sites prior to establishing petroleum drilling rigs much of this same information is required. Aircraft are also used to follow the movement of large ice features (several miles across) as indicators of ocean currents, and for iceberg patrol.

Weather, logistics, and economics dictate the success of many aerial reconnaissance missions. Furthermore, since aerial ice reconnaissance is largely subjective, the accuracy of the observations will be largely contingent upon the training and experience of the observer. The observer is also limited in the size of the area which he can view effectively, usually a distance of about 15 miles on either side of the aircraft. Added to this is the possibility of location error due to navigation difficulties, particularly in Arctic and Antarctic regions.

Early experiments involving interpretation and use of satellite imagery have already demonstrated the feasibility of using space vehicles to complement and supplement the conventional ice reconnaissance and surveillance program, particularly as this program is applied to economic needs. Project TIREC, a joint U. S. – Canadian program to coordinate aerial and surface ice observations with TIROS IV ice photography (Figure 2.6-9), led to the development of satellite ice reconnaissance techniques which are now being applied operationally. Where only point observations from shore stations are obtained, satellite imagery is used to "tie in" these observations (Figure 2.6-10) and obtain a complete picture of the shoreline extent of ice. Locally, this information can be used to predict ice breakup or formation along coastal areas where small commercial or recreational activities such as fishing are of interest. Leads, polynyas, and other open water features 1/2 mile or larger can also be detected in satellite imagery. On a larger scale, satellite photographs of the Great Lakes region have been used as an aid in preparing forecasts of ice breakup for commercial shipping activities (Figure 2.6-11). In the Gulf of St. Lawrence satellite ice photography provided ice information sufficient for ship routing into Newfoundland as early as 1961. More recently, satellite data were used to correct a forecast of ice conditions in the same area (Markham, W. E. and Popham, R. W., 1963). Experience has shown that, over areas of major economic interest, satellite photography suitable for ice reconnaissance purposes can be obtained at least once or twice per week, sometimes more often. This is enough to give a good indication of the ice extent and stage of formation or breakup.

Satellite ice observations can also play a role in detecting and tracing ocean currents. During Project

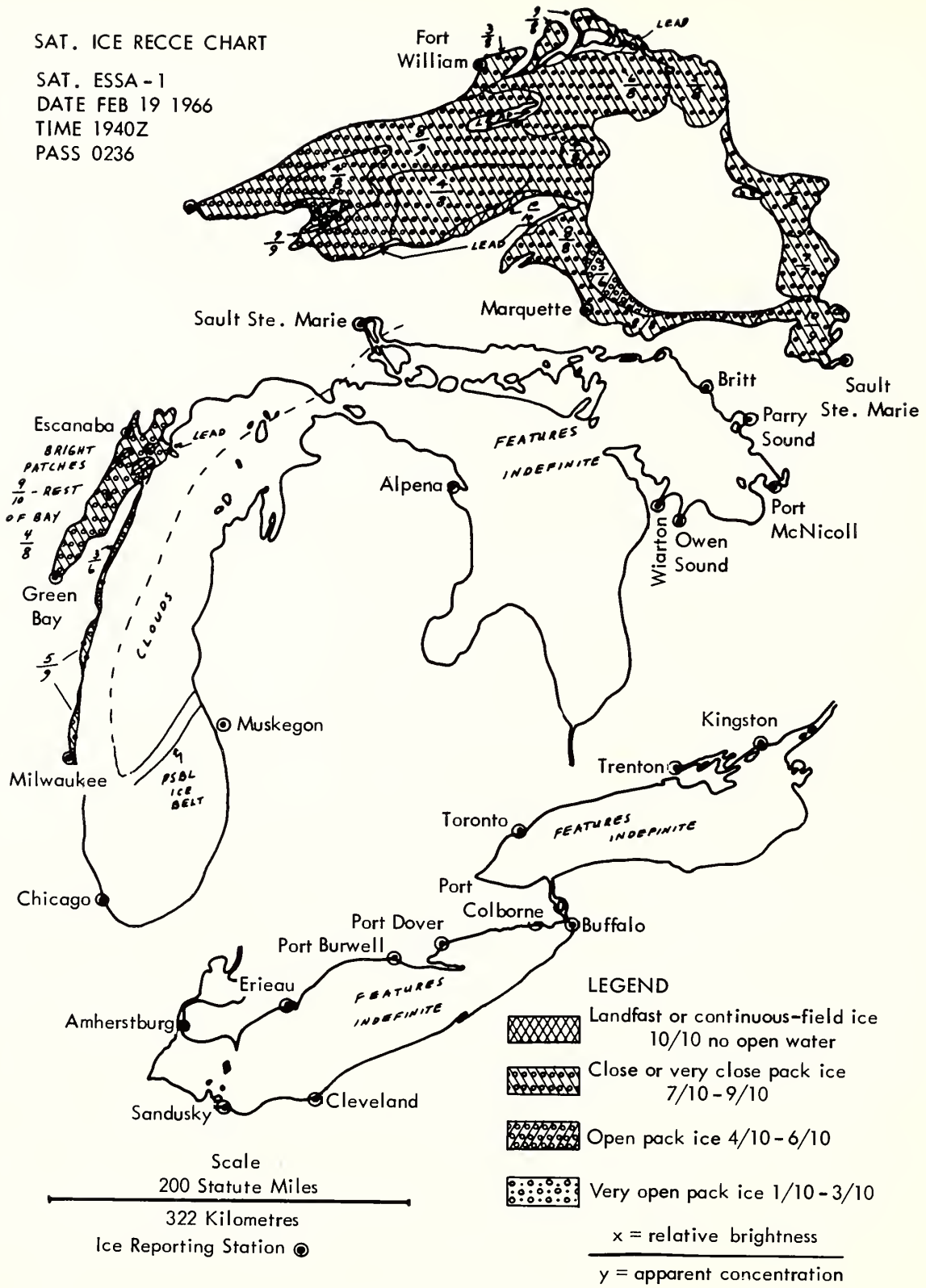

Figure 2.6-11. One of several satellite ice reconnaissance charts transmitted on facsimile to stations in the Great Lakes region during 1966. Such information complements conventional aerial, ship and land stations reports of ice conditions, contributing to more effective ice forecasting.

Figure 2.6-12. Sea ice off the east Newfoundland coast, photographed by TIROS IV and by U. S. Navy aircraft during Project TIREC. "Swirls," or eddy currents, produced by the confluence of the Labrador Current and the northeastern extension of the Gulf Stream are visible because of the presence of ice. High-resolution satellite imagery provides an excellent opportunity for detecting and studying such current eddies in areas where ice features can be used in tracers.

TIREC, an ice area off the east Newfoundland coast was photographed simultaneously by aircraft and by satellite. The swirling eddy patterns seen in Figure 2.6-12 are produced by the confluence of the Labrador Current and the northeastward extension of the Gulf Stream. The patterns are visible because of the presence of ice. Other similar patterns have been observed in satellite, radar, and infrared imagery in other areas.

Another example of sea ice movement due to current effects is shown in Figure 2.6-13. The ice is observed to drift eastward and northward from the southern and western Gulf of St. Lawrence, then out of the Gulf through Cabot Strait and southward along the east coast of Cape Breton. This series of pictures is only a sample of the many which have been obtained and examined in connection with sea ice studies. In one study satellite photographs obtained on two consecutive orbits were examined stereoscopically and the direction and rate of movement of specific sea ice features was measured. In other photographs the rotation and drift of individual floes in the St. Lawrence River were observed; those closest to the shore were moving counter to the direction of the main current. More recently, the rotation and movement of large ice floes caught in the East Greenland Current were followed for several days using Nimbus II photographs.

The movement of ice islands in the Arctic has long been used as a key in determining the drift of Arctic pack. To determine whether visual identification could be accomplished from satellite altitudes the position and movement of three Arctic ice islands were plotted from conventional data. Nimbus I pictures of the areas in which the islands were observed were closely scrutinized, but no evidence of their existence could be found. Since these islands are generally much thicker than the surrounding pack, and remote system which could be used to determine ice depth (and preferably through clouds) will have to be employed. Both radar and microwave systems might be applied for this purpose.

The experience gained through nearly seven years of studying satellite ice imagery provides the basis for specifying further spacecraft experimentation in this field. In particular, improved resolution and contrast over that already achieved with TIROS II narrow angle cameras or in Nimbus I AVCS photography is needed. Aerial iceberg patrols could be substantially reduced, possibly eliminated, with ground resolution of 25 feet. Requirements for tactial aircraft support of ship operations could also be significantly reduced with this same resolution. With a ground resolution of 100 to 1000 feet, the necessity of conducting long-range reconnaissance flights to obtain ice information for forecasting purposes, or to detect and measure ocean currents by tracking large ice floes or ice islands, could be largely eliminated. Resolution poorer than this, however, would not contribute much more to what we already can do using existing satellite photography.

Coincident with improvements in resolution, the contrast or grey scale range of the photography

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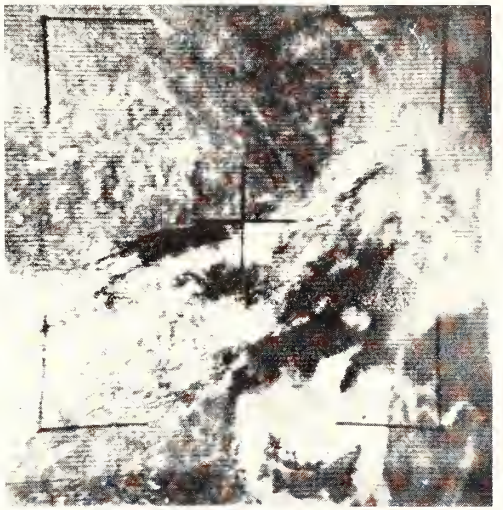
ORBIT 793, APRIL 4, 1962



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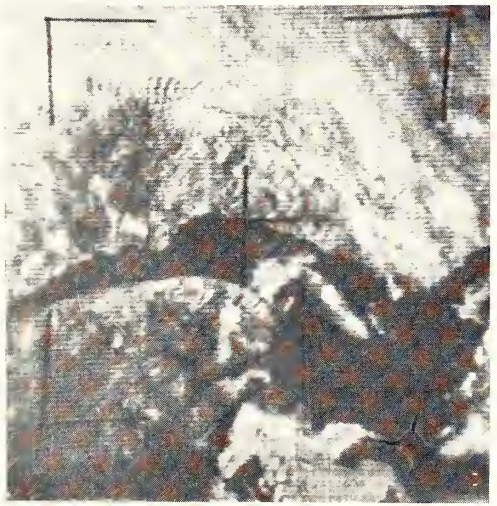


ORBIT 822, APRIL 6, 1962

ORBIT 835, APRIL 7, 1962

ORBIT 908, APRIL 12, 1962

Figure 2.6-13. A series of TIROS IV satellite photographs taken during Project TIREC, illustrating how the movement of sea ice features can be followed using satellite imagery. The ice is observed to move in an easterly and northeasterly direction, out of the Gulf of St. Lawrence, through Cabot Strait, then southward along the east coast of Cape Breton. More recently, the movement of large ice floes along the east Greenland coast has been followed in Nimbus II satellite pictures.

should be improved. The presence of thin ice, or old ice with large meltwater puddles forming on the surface, and relatively thick ice which is degenerating the absorbing water, cannot be detected with current visual sensors except in rare circumstances (Figure 2.6-14). The use of microwave and infrared sensor systems may prove most helpful under these circumstances. Microwave sensors may also be applicable to the detection of ice features in polar regions when cloud cover and the long polar night preclude visual surveillance for extended periods of time.

The use of color photography to study tonal variations in ice features would be most helpful, especially if obtained in conjunction with black and white imagery from the same vehicle. In populated areas the accumulation of combustion by-products falling on the ice surface accelerates ice breakup by decreasing the reflectivity of the ice surface, thus permitting greater absorption of sunlight. Waste discharge from industrial plants has the same effect; however, the color of the pollutant may vary. In polar regions, ice age and thickness are often visually determined by color. Particularly evident is the "ice-blue" color of thick winter ice, ice which persists from year to year. This type of ice is very hard, usually a result of gradual cooling and compression processes.

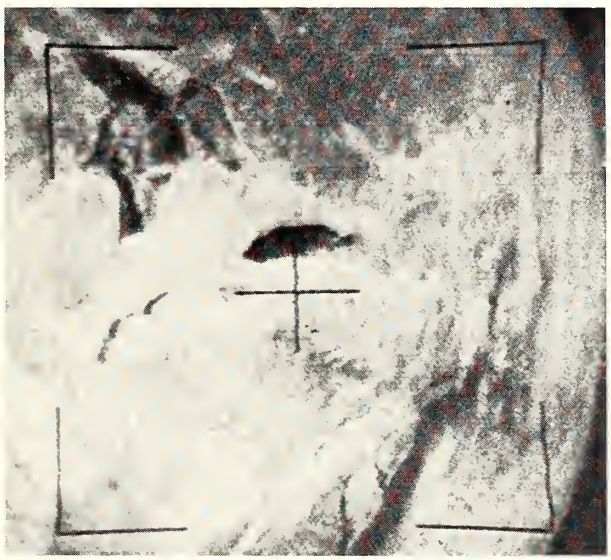


Figure 2.6-14. ESSA 1 photograph of snow cover on thin ice in Lake Erie. Thin ice or slush cannot be detected with current satellite TV systems except by chance light reflection off the ice surface or, as in the case illustrated here, when a snowstorm deposits a cover of snow on its surface. The use of satellite-borne microwave or infrared systems may help resolve the problem of detecting these types of ice.

Supporting "ground truth" observations, or more precisely, "aerial truth" observations, would be helpful in key-coding tonal variations in ice features observed from satellite altitudes. High-altitude aerial photography obtained in conjunction with conventional low-altitude ice reconnaissance helped resolve many of the discrepancies which existed between aerial ice reports and satellite ice analyses during Project TIREC. However, the resolution and contrast of the TIROS IV camera system did not permit establishment of a reliable ice "color code" applicable to later satellite photography.

2.6.2.6 Spacecraft Interrogation. Although the application of spacecraft interrogation techniques was not a part of this study – requiring a major study of its own – it is necessary to consider it in some depth because of its potential usage in so many areas. The potential interrogation of systems aboard balloons, aircraft, rockets, and spacecraft as well as from land and water based devices offers unsurpassed opportunities for conventional data collection for the analysis of natural resources and the earth environment. This section will be confined to some possibilities which exist in oceanography.

A. Sea State

Wave height gauges and sea surface anemometers, with appropriate modifications, could be interrogated by spacecraft. These data could also be correlated with observations obtained by other remote sensing techniques, such as radar or microwave systems. Assuming that proper consideration is given to the quantity and geographic distribution of such instruments, these systems could provide the point source data necessary for adequate quasi-synoptic analyses of regional basins. The interrogation vehicle could be either a geo-stationary satellite such as ATS, or an orbiting satellite such as Nimbus. The former has the advantage of more frequent read-out if the surface units are located in tropical or mid-latitudes, while the latter would be necessary for interrogating systems located at high latitudes. Systems costs per unit appear to be less for devices which could be interrogated by orbiting spacecraft.

B. Water Masses

Stationary and free floating buoys with instruments mounted on mooring or trailing cables or lines are commonly used by oceanographers today. Development of satellite systems which could be

used to interrogate such buoys would lead to the collection of an unprecedented quantity and type of information invaluable for regional water mass differentiation and current studies. Such information would be especially valuable even along such relatively accessible ocean areas as the east and west coasts of North America. The combination of such sampling techniques with quasi-synoptic remote sensing data could eventually provide a level of understanding of regional oceanic variations never before attainable, particularly along the tracks of major storms. Geo-stationary spacecraft systems may be more practical than orbiting satellites because of their greater flexibility for obtaining time-sequence data on a real time basis.

C. Ocean Tides and Storm Surges

Interrogation of submerged stationary buoys with floating antennas could be an ideal method for determining the variations of ocean tides and storm surges on a global scale. Since ESSA has developed a deep-sea submerged buoy technology and since time-lag pressure sensors exist to detect such information, the creation of an early operational system is feasible. With geo-stationary spacecraft interrogating such systems at suitable time-intervals, the acquisition of world-wide ocean tide and storm surge information could be practical within a few years.

2.6.2.7 Proposals for Future Consideration.

A. Beach and Shoal Morphology

The kind of analyses desired for beach and shoal morphology requires ground resolutions of better than 1 meter. However, useful information can also be gained from photographic systems with resolutions ranging from 5-30 meters, if related to large coastal features.

B. Coastal Damage Surveys

There is a need to resurvey and rechart coastal areas and waters promptly after violent storms, seismic sea waves, and earthquakes have altered inlets, harbors, offshore bars, islands, reefs, beaches, and other features which might obstruct waterways and impede shipping and industrial activity. Areas assigned the highest priority in resurvey schedules are those sustaining the most damage and those having the highest population densities and greatest economic importance. Aerial photography has been used to initially assess amount of damage and geomorphic change and to determine the priority of resurveys, but even this modern method is a comparatively slow technique because of the time required to process and interpret the large volume of film when a large area is involved. High resolution imagery from spacecraft in conjunction with minimum delay readout by means of communication satellites could provide the needed preliminary coverage quickly to determine areas of highest priority.

Relatively low resolution imagery could be used to detect large area morphologic changes caused by earthquakes, such as the Good Friday upheaval in Alaska in 1964. However, the detection of smaller features, such as the shift of bars or the closing of inlets, will require resolutions of 30 meters or less, while analysis for the destructive erosion of a beach would require very small spatial resolutions.

Surveillance of all the earth's shorelines could be accomplished by photography from a polar-orbiting satellite. However, suitable techniques will be needed to select the proper coastlines and to limit the image collection after a disrupting event. Storm and earthquake damage data along the coastal regions of other nations should also be provided to enable them to accomplish timely disaster relief, rehabilitation, and, eventually, recharting.

C. Storm Surges

A storm surge is a build-up of coastal water associated with a violent storm, such as a hurricane, typhoon, or intense cyclone. The area and height of a storm surge varies with the area of the storm, the speed of the winds, the distance the storm travels across the ocean (fetch), the local coastline configuration, and the bottom topography. Normally, these surges, ranging up to 20' in height at the coast, are not detectable until they strike land and create an abnormally high reading on a tide gauge. Experience gained in correlating tide gauge readings with storm analyses and numerical hydrodynamic models have created a prediction capability. Methods are needed to detect these changes in ocean levels while these surges are still at sea to provide initial data input into the numerical models. There is some hope that radar and laser distance measuring instruments may be able to detect such phenomena from spacecraft. Also, the radar scatterometer (Pierson, Tick, Baer – 1966) is considered as a possible detector since suitable data analysis procedures have been developed.

D. Sea Level and Sea Slope

Sea level is defined (for this proposal) as a fictitious

surface generated midway between the crests and troughs of wind waves. This surface is dynamic and does not ordinarily coincide with a theoretical surface related to the shape and rotation of the earth because of ocean currents, tides, and variations in atmospheric pressure and wind. Information on these sea level anomalies is desired on a global scale, and the collection of such information will obviously require new techniques.

Fast ocean currents are estimated to have a slope of about 1 part in 10^5, slower currents 1 part in 10^6 or less. Furthermore, ocean currents have seasonal variations as well as higher frequency changes, often of a meandering nature. Therefore, a slope measuring capability of about 1 part in 10^7 is desirable.

There is a well established tide prediction capability at places where tide observations have been made. Tide observations in the open ocean are required to obtain a world wide tidal pattern. Mid-ocean tides are believed to be small, on the order of about a foot but varying from place to place. An observational accuracy of about 5 cm in relative height would be needed to obtain a time series suitable for tide analysis. This degree of precision is considered beyond the present state of the art.

Sea level changes due to variations in atmospheric pressure are probably of the same order of magnitude. Changes due to winds are superimposed. These variations are harder to define, depending in part on the horizontal and time scales, and are possibly non-linear with wind velocity.

If the above causes of sea level variations, including storm surges, can be accounted for, the geophysicist will be interested in examining the residuals to determine if they are transient, cyclical, or persistent and if they are pertinent to the geodetic determination of sea level.

E. Seismic Sea Waves

Seismic sea waves expand from their seismic source across an ocean basin with the energy distributed vertically to the sea floor. In the open ocean the wavelength is of the order of 100 miles and the surface amplitude of the order of one foot, such waves can pass a ship at sea unnoticed by those on board. The velocity in deep water can be as high as 600 mph, diminishing in speed with depth, where the velocity is determined solely by water depth. As they approach the coasts they can build up to tremendous heights, causing enormous damage.

If systems aboard spacecraft can be developed to determine information on sea level and sea slope, they would probably be able to detect seismic sea waves. The required information includes the detection of the expanding wave patterns and refraction effects caused by subsurface ridges and sea mounts. However, since seismic sea waves are transient phenomena, the probability of detecting them from an orbiting spacecraft would be extremely low. The probability level, however, could be raised by using a spacecraft in synchronous orbit.

Present seismic data are transmitted to the central collection facility at Honolulu by submarine cable. Interrogation of the sensors by satellite is worthy of investigation, and if it appears feasible, many more sensor systems could be spread over the Pacific with an expected significant improvement in understanding the transmission problems and in the resulting warning capability, (see Section 2.9.2).

2.6.3 Related NASA Programs

The objectives of the NASA program in oceanography are to identify, test, and evaluate those techniques which can be applied to earth-orbiting spacecraft and to provide meaningful and useful oceanographic data relative to the following:

- Economy and safety of ocean transportation
- Location of productive fishing areas
- Development and testing of new techniques for displaying and using synoptic oceanographic data on a global basis which will enhance understanding of the properties and behavior of the oceans

To carry out the objectives of this program the U.S. Navy has been requested by NASA to consider the oceanic data requirements of the civilian oceanographic community. A Spacecraft Oceanography Project (SPOC) was established with the U.S. Naval Oceanographic Office in Suitland, Maryland in late 1965 to comply with this request. An Ad Hoc Oceanography Advisory Committee, composed of government and university scientists, has been formed to aid in defining user requirements, to help delineate the potential space techniques that could contribute to the various problems, and to establish priority areas for research and development. Consequently, NASA has provided contractual funding through SPOC to support various R&D projects in government, universities, and industry. (SPOC, 1966).

The early phases of the NASA-SPOC oceanographic program are devoted to instrument definition and the use of aircraft for determining sensor feasibility. The later phases of the program will involve instrument development and spacecraft ex-

periments. The aircraft program will be used to evaluate the following type sensors: (1) Photography – optical (2) IR imagery, spectroscopy, and photometry (3) Passive microwave radiometry and imagery (4) Radar imagery, altimetry, and scatterometry (5) laser altimetry and (6) absorption spectroscopy.

The currently identified potential experiments and candidate flight missions are listed below.

A future manned space station is being considered for exploring the feasibility and capability of remote sensing devices to detect sea state, sea surface temperature, ocean currents, surface winds and the presence of minerals and marine life.

Nimbus B and D (1968-70)

Instrumentation	Application
Interrogation, Recording and Location System	Collection of oceanographic data from instrumented platforms
Infrared Radiometer/Spectrometer	Sea surface thermal mapping

Advanced Technological Satellite ATS-C (1967)

Instrumentation	Application
Omega Position Location Experiment	Collection of oceanographic data from instrumented platforms

Earth Resources Survey Satellite (ERS)

Instrumentation	Application
Infrared Imager	Sea surface thermal mapping
Passive Microwave Imagery and Radiometry	Sea surface thermal mapping
Passive Microwave Radiometry and Imagery	Water Vapor
Metric Camera, Panoramic Camera, Ultrahigh Resolution Camera, Radar Imagery, Infrared Imagery	Ice surveillance
Radar and Laser Altimetry	Ocean wave
Metric Camera, Panoramic Camera, Ultrahigh Resolution Camera, Radar	Shoals, coastal morphology
Radar Scatterometer	Sea state
Multiband Synoptic Camera	Ocean currents
Infrared Radiometer and Imagery	Ocean currents
Radar and Laser Altimetry	Sea Level and sea slope
Absorption Spectroscopy	Biological phenomena

Apollo Application "AAP-A" – 1970

Instrumentation	Application
Multiband Synoptic Photography	Ice surveillance
Multiband Synoptic Camera	Ocean currents
Metric Camera, Panoramic Camera	Ocean currents
Infrared Radiometer and Imagery	Ocean currents

Apollo Application "AAP-B" and /or "D"

Instrumentation	Application
Infrared Imager	Sea surface thermal mapping
Passive Microwave Imagery and Radiometry	Sea surface thermal mapping
Infrared Radiometer/Spectrometer	Sea surface thermal mapping
Passive Microwave Radiometry and Imagery	Water vapor
Metric Camera, Panoramic Camera, Ultrahigh Resolution Camera, Radar Imagery, Infrared Imagery	Ice surveillance
Radar and Laser Altimetry	Ocean wave
Metric Camera, Panoramic Camera Ultrahigh Resolution Camera, Radar	Shoals, coastal morphology
Radar Scatterometer	Sea state
Multiband Synoptic Camera	Ocean currents
Metric, Panoramic Camera	Ocean currents
Infrared Radiometer and Imagery	Ocean currents
Radar and Laser Altimetry	Sea Level and sea slope
Absorption Spectroscopy	Biological phenomena

2.7 GEODESY – GEOMETRIC AND GRAVIMETRIC

2.7.1 Description of Scientific Field Considered

Geodesy, for purposes of this report, may be defined as that branch of the environmental sciences concerned with determining the exact size and shape of the earth's land masses, and variations in terrestrial gravity. Geodesy employs the principles of mathematics, astronomy, and physics to establish precise three-dimensional control points on the earth's surface, measured in various ways (tri-with the strictly geometrical relationships of the earth's surfaces, measured in various ways (triangulation, trilateration, electronic surveys, etc.) to determine the size and shape of the earth and the precise location of specific positions on the earth's surface. *Gravimetric* geodesy utilizes measurements and characteristics of the earth's gravity field as well as theories regarding this field to determine the shape of the earth.

The equipotential surfaces in the neighborhood of the physical surface of the earth are of special interest in geodesy, especially the one which represents the surface of the oceans when free of the perturbing effects of tides and currents. Such an equipotential surface is known as the *geoid.* Since observations of satellite orbits have to satisfy both the gravitational model and fixed geometric relationships with respect to tracking stations, a link is provided between gravimetric and geometric problems in geodesy. It is the ultimate scientific and operational goal of geodesy to express both the geometric and gravimetric relationships in a common worldwide reference frame which must be oriented unambiguously with respect to the inertial (astronomic) coordinate system.

There is growing recognition of the fact that processes related to the earth in its entirety require the various disciplines in the earth sciences to conduct their efforts – at least partially – on a global basis. Geodesy is expected to develop its capabilities accordingly. By virtue of several theoretical developments, geodesy, in addition, finds itself confronted with trends which mean no less than a revolution in its theoretical foundation, thereby demanding the acceptance of new measuring tools. Because of the geometrical and dynamic characteristics of their orbits, artificial satellites enable geodesy to interconnect the results of its geometrical and physical studies on a worldwide basis using three-dimensional models which are based on a minimum of a priori hypotheses.

If the modern concepts in geodesy are considered in connection with the possibilities offered by satellite vehicles, it becomes evident that a logical, unified approach to one of the basic problems of geodesy can now be envisioned. This has, as its ultimate purpose, the establishment of all points on the physical surface of the earth in terms of a world-wide three-dimensional coordinate system, with the origin at a point representing the center of mass, and one of whose axes is the rotational axis of the earth. The significance of three-dimensional geodesy becomes most evident in connection with geodetic satellite triangulation which, by the very nature of its geometrical and physical contents, demands three-dimensional solutions.

2.7.2 Proposals and Related Requirements

2.7.2.1 Scope. The growing number of space vehicles and the increasing potential of remote sensors provide an attractive means for solving geodetic problems. A selection of the possibilities offered is listed in Table 2.7-A. Proposals (a), (b), (c), and (d), listed under 1 (Geometric-gravimetric experiment) could probably be combined into one payload. This collective proposal will be described below, under Section 2.7.2.2.

The possibility of successfully completing Proposal Number 1 must be viewed in light of the present worldwide satellite triangulation system. The feasibility of such a system has been proven in the past two years by the Coast and Geodetic Survey, in cooperation with the Department of Defense, with the establishment of a three-dimensional satellite triangulation net covering a large portion of the North American continent, and extending to Europe. Observations to establish the world-wide network were initiated following NASA's successful launch of the geodetic satellite PAGEOS; this net is expected to be completed by 1970. The ultimate accuracy obtainable with such a system is one to two parts in 10^6.

The purposes of such a three-dimensional, strictly geometrical triangulation are:

(a) To provide a worldwide reference net to which all geodetic-topographic products can be related. Such a reference system would achieve economy and permanence in the collection and recording of data essential to the development of the earth sciences.

(b) To replace the classic, time-consuming, long-arc triangulation methods of determining the shape and size of the earth, with a more

Table 2.7-A — List of Proposals for Geometric and Gravimetric Geodesy

Proposal Number	Description	Special Orbit	Comment
*1#	Geometric-gravimetric experiment		See 2.7.2.2
(a)	Determination of three-dimensional geodetic control	Polar circular 250 km	—
(b)	Topographic mapping	Polar circular 250 km	—
(c)	Map revision	Polar circular 250 km	—
(d)	Geoidal contouring	Polar circular 4000 km	—
2	Gravity gradient measurements	—	—
3	Geodetic scale determination and monitoring of continental drift	—	Laser ranging from ground to corner reflectors on satellites
4	Pole movements	—	Laser ranging from Earth to corner reflectors on Moon
5	Improved Moon orbit	—	Laser ranging from Earth to corner reflectors on Moon
6	Determination of the gravity field of the Moon	Polar Moon	—
7	Determination of the three dimensional geometry of the Moon's topography	Polar Moon	—

#Requirements of major importance
* Proposals selected for detailed discussion.

economical and theoretically superior approach, in order to meet the requirements for modern astronomy and space research.

(c) To produce unified, three-dimensional reference nets on all accessible land masses, thus eliminating the troublesome discontinuities in map and survey systems which occur over most national frontiers and which seriously hamper the development of many nations. Such continental triangulation nets will provide the necessary control for numerical photogrammetric aerial triangulation, executed from extremely high-flying aircraft or satellites, to further intensify the geodetic control pattern in local areas in order to provide control density in accordance with specific topographic mapping requirements. The creation of such a control pattern will provide the most economical approach to the worldwide mapping programs of many groups, and at the same time furnish the geodetic community with a data library for fast-response mapping capability.

(d) To establish the necessary geometric fidelity for a worldwide system of satellite tracking stations as a prerequisite for the accurate determination of satellite orbits, which, in turn, will provide data ideally suited for analyzing gravimetric and related geophysical parameters.

The basic problems to be considered are the use of satellite-borne photography for establishing geodetic control for a variety of users involved in supporting topographic mapping, and acquiring large scale photography for map compilation. The techniques involved are virtually the same as those under development in computational photogrammetry. Since the lowest feasible height for satellite orbits

is between 200 and 250 km, the troublesome problems of extended photogrammetric aerial triangulation are avoided because the coverage of a few photographs corresponds to the spacing of the control points. An artificial satellite with several cameras on board, therefore, along with a device for the determination of scale, will provide geodetic control and data of value to agencies involved in the production of suitably scaled topographic maps.

A new tool of considerable theoretical and economical value becomes available with the tracking of satellites from stations positioned by the aforementioned geometric satellite triangulation method. When equipped with radar-altimeter or laser ranging equipment, such satellites can measure with a high sampling rate, the separation between satellite positions and the surface of the ocean. The abundance of data obtained with such geoid-profiles, at different times in order to determine oceanographic effects, would provide, in a most desirable form, the badly needed gravimetric information at sea. In addition, these data would, even if obtained only locally, be of assistance to those concerned with the study of off-shore regions for locating geological features.

2.7.2.2 Geometric-Gravimetric Experiment. The purpose of the proposed experiment is the exploration of the potential of high precision metric photography taken from earth-orbiting satellites in combination with electro-optical ranging and time-correlated stellar photography for geodetic purposes. These data will be of value to those organizations engaged in topographic mapping and related activities.

The scientific objectives of the experiment are:

(a) Establishment of three-dimensional geodetic control in selected areas of the earth's land masses, which is related unambiguously to the right ascension-declination system and tied to the worldwide geodetic reference system that will be established under the National Geodetic Satellite Program sponsored by NASA.

(b) Investigation of the requirements of space photography for topographic mapping of remote areas of the earth at small and medium scales, specifically for determining essential planimetric and elevation control.

(c) Establishment of the potential of space photography in providing three-dimensional control for the evaluation and elimination of dynamic distortions of high-resolution panoramic material. This should provide the basis for an economical method of making map revisions.

(d) Determination of the geometric shape of those portions of the earth's surface which are covered by oceans, thus providing a geometric method for determining the undulations of large portions of the geoid and eventually simultaneously providing information about any systematic deviations of the surfaces of the various oceans from an equipotential surface.

Methods and instrumentation systems for accurately determining the geometry of the satellite orbit itself are available as a result of efforts conducted in satellite geodesy. If, therefore, a system for measuring the height of the satellite over the ocean with sufficient accuracy can be developed, both geodesy and oceanography could be served by determining geoid profiles while at the same time measuring the magnitude of tidal effects and their progress with time over the ocean surface.

A. User Requirements

A major source for requirements are government agencies responsible for establishing geodetic control and topographic maps within the conterminous United States and its possessions. The main agencies with such responsibilities are the Coast and Geodetic Survey and the U. S. Geological Survey, respectively.

The investigators most likely to require geodetic and cartographic knowledge are those working in the geological and geophysical disciplines who are concerned with the origin of the earth and its resources. Improved geodetic knowledge is needed, specifically to:

(1) Indicate the extent of density differentiation in the interior and the departure of the density distribution from hydrostatic equilibrium, which results in variations of gravity and topography over the surface; and

(2) Indicate the nature of disturbing effects on a planetary scale and the nature of the earth's response to these effects, as reflected, for example, in temporal variations of the position of the pole and changes in the rate of rotation.

B. Basic Considerations in the Design of the Experiment

In order to satisfy an accuracy requirement of ±3 meters (1 sigma), the theoretical limits of the photogrammetric triangulation method (executed over extended areas of the earth) would have to be at-

tained. It is desirable, therefore, to support the photogrammetric terrain cameras with auxiliary equipment in the form of stellar cameras, in order to provide additional absolute orientation parameters. Also, altimetric measurements (measurements of the clearance between orbital vehicle and earth's surface) are needed for determining absolute scale at suitable intervals. Both types of information are essential in order to compensate for the otherwise unfavorable error propagation which is typical of extended three-dimensional photogrammetric triangulations.

It is then obvious that first priority must be given to the development of a metric camera system capable of producing, within the mission constraints, the highest possible accuracy for determining the three coordinates of both spacecraft camera exposure stations and the network of photo-identifiable points on the surface of the earth.

A back-up mapping camera system appears necessary, because a second frame system would permit acquisition of metric photography in both color and black-and-white. This feature is attractive from the standpoint of information content, especially with respect to multi-band synoptic experiments.

The sensor package of the proposed experiment will consist, consequently, of the two frame cameras, two stellar cameras, twin convergent panoramic cameras, and one bore-sighted altimeter system (RADAR and/or LASER). All of these sensors must ultimately be calibrated simultaneously as a single package and correlated to the mission time standard. In addition, for in-flight calibration purposes, it is imperative that the capability of photographing the star background with both stellar and frame cameras be provided.

C. Selection of Camera System

From the large family of vertical frame, convergent frame and convergent panoramic cameras presently available, the system described in Table 2.7-B has been selected as especially suited for the task under consideration. Figure 2.7-1 is a graphic abstraction of the suggested method and Figure 2.7-2 is a possible arrangement of a technically feasible system

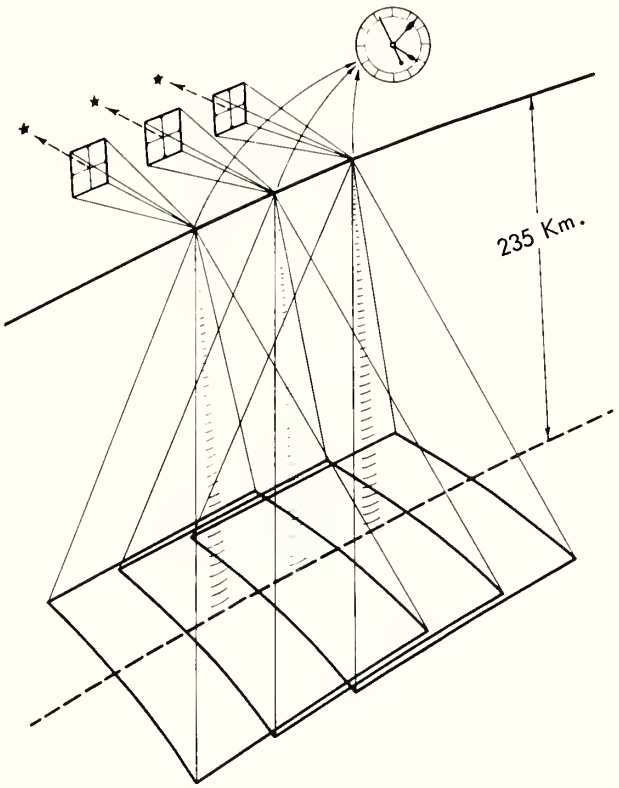


Figure 2.7-1. The principle of satellite photogrammetry, showing schematically the significance of terrestrial and celestial photography, time, and range measurements.

Table 2.7-B – Camera System Parameters for Geometric-Gravimetric Experiment

Parameter	Vertical Frame Camera	Supplemented by: Convergent Panoramic Camera
Focal length	305 mm	610 mm
Film width	240 mm	75 mm
Format length (in line of flight)	370 mm	60 mm
Format width (perpendicular to line of flight)	230 mm	760 mm
Tilt	0°	15-22°
System resolution including film (lines per mm)	60-80	120 plus
Type of film	black, white and color	black, white

using partially available components.

The use of convergent frame cameras was considered undesirable, not only from the photogrammetric standpoint, but because the raw material will be used by specialists in other disciplines such as geology, geography, agronomy, botany, oceanography, etc. Such investigations are served best by vertical photography, eliminating the need for any complex rectification.

The panoramic system has the task of providing high resolution supplementary stereo coverage for information necessary for cartography, for large scale mapping, and other detail studies. The choice of color and black-and-white photography will not only best serve the cartographic purposes, but should serve as welcome comparison standards for any additional simultaneously acquired spectra-zonal photography.

D. Auxiliary Data Collection Systems

Stellar cameras, a system clock, and an altimeter system would also be needed as auxiliary data collection systems. Stellar cameras would be necessary to compensate for the unfavorable error accumulation in extended strip or block triangulation. Photography with these cameras can be based either on sun or star photography or on both. In either case, the auxiliary camera system must be designed in such a way as to optimize the angle of view and focal length requirements. A balanced system which will provide sufficient angular resolution may be obtained with a 70 x 70 mm format, when combined with a 6 inch focal length.

The time intervals between the exposures of the ground cameras must be measured to 500 microseconds or better in order to strengthen the orbital constraints. The absolute time for the exposures of

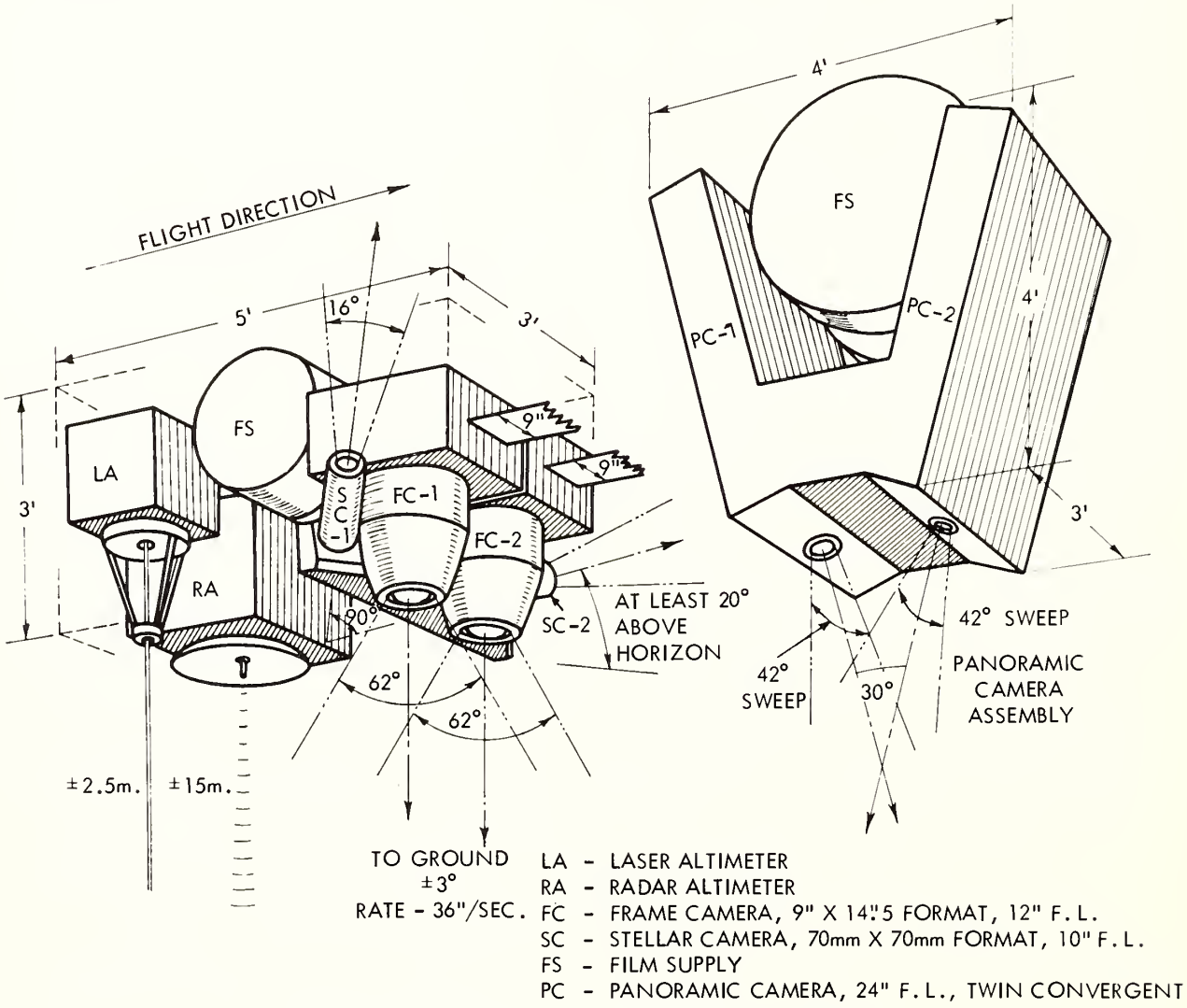


Figure 2.7-2. An illustration of the proposed camera system.

star cameras must be known to at least 0.05 second. These problems are best served by a system clock, which is, generally speaking, needed in all space experiments.

An altimeter for measuring the clearance between the vehicle and the surface (although not necessarily at each photograph) is an indispensable requirement, because it will provide the needed scale. A pulsed altimeter, synchronized with the midpoint of shutter opening of the frame camera, must have a resolution comparable to the overall systems accuracy. Both radar and laser are considered feasible. Requirements in terms of weight, volume and power of such a system are under study.

E. Expected Accuracies of the Proposed Systems

The identification of detail for high contrast targets is approximately proportional to the corresponding system resolution. According to theoretical studies the following ground resolution might be achieved (based on 70 lines/mm for vertical frame cameras, 120 lines/mm for panoramic cameras):

Orbital Height		235 km
Scale	Frame	1: 800,000
	panoramic	1: 425,000
Ground detail	frame	12 m
Resolution for high contrast targets	panoramic	3.5 m

The overall accuracy of the triangulation system can be approximated by taking the mean unit error of the film (which, after adjustment will be approximately ±5 microns) and multiplying it by twice the scale.

Thus one obtains:

Orbital height	235 km
Accuracy for ground control in all three coordinates obtained from frame material	±8 to ±10 m

F. Extent of Coverage

To cover the land masses of the earth, the number of photographs which must be taken, and the film weight (without reels and magazines) which must be recovered, are approximately:

	Frame	Panoramic	Star
No. of photographs	10^4	5×10^4	10^4
Film weight (lbs)	250	900	15

G. Summary and Conclusions

Because of the large film weight necessary for panoramic coverage and the tremendous amount of reduction effort, serious consideration should be given to directing its application towards investigating selected areas only.

In numerous informal discussions between representatives of various governmental agencies and leading industries, an understanding was reached that the aforementioned system presented a technically feasible and desirable approach to the problem under consideration.

Orbital requirements may necessitate separate missions for the proposed experiments. Because of the necessity of having a star camera on board in both a gravimetric or geometric experiment, and because there is a close relationship between the technical goals to be accomplished, the combination of all sensors suggested here appears to be optimum from the standpoint of instrumentation utilization.
For further details see (Schmid, 1966).

2.7.2.3 Proposals for Future Consideration. Proposal Number 2 in Table 2.7-A (the use of gravity gradiometer in earth orbit) appears, despite its theoretically attractive principle, rather marginal when compared to information from the evaluation of orbital tracking. However, laboratory tests have confirmed that an accuracy in the order of 0.05 eötvös units or 5×10^{-11} gal/cm can be obtained. This is considered essential for sensing the earth's gravitational field to the same extent that it has already been defined.

With the forthcoming improvements in laser ranging as applied to satellites, the feasibility of proposals 3, 4, and 5 appear to be promising. Proposal 3 could be used to supplement the present worldwide satellite triangulation system. This proposal has been successfully pioneered by NASA and others.

With the experience gained in successfully completing the geometric-gravimetric experiment (proposal 1), methods will become available for solving the problems associated with proposals 6 and 7. In this connection, it is especially important to realize that the technology required for proposals 6 and 7 can be developed from the hardware necessary for Proposal Number 1.

The proposals listed in Table 2.7-A are somewhat limited with regard to gravimetric geodesy. At present, a great amount of effort is being expended by private and public agencies, employing artificial satellites, in determining the gravity field of the earth.

Upon the completion of the present worldwide geometric network, the re-evaluation of the data obtained for gravitational studies may be worthwhile, and may dictate what type of further investigation would be required.

2.7.3 Related NASA Programs

The National Aeronautics and Space Administration is responsible for conducting a National Geodetic Satellite Program that will satisfy the geodetic satellite requirements of the scientific community.

The objectives of the National Geodetic Satellite Program are: (1) to develop a unified world datum (control points to 10 meters in a geocentric coordinate system), (2) to improve the description of the Earth's gravitational field, and (3) to compare and correlate the existing high-accuracy instrumentation systems. The Department of Commerce, the Department of Defense and NASA are the main participants in the program which includes both passive and active satellites. Their efforts are supplemented by those of the Smithsonian Astronomical Observatory and the international community.

The first active geodetic satellite, GEOS I, was launched on November 6, 1965, into an Earth orbit with an apogee of about 2,300 km, a perigee of about 1,100 km, and an inclination of 59°. GEOS I was fully operational until December 1, 1966 and more than 100 ground observational stations continuously collected data from this satellite. Five basic observational systems were used with GEOS I: GSFC Range and Range Rate, SECOR, Doppler, Flashing Lights, and Laser. The passive geodetic spacecraft, PAGEOS, was successfully orbited in June 1966, to support the establishment of a worldwide geometric network. GEOS-B is planned for launch at the end of CY 1967 into a 1,500 km by 1,100 km orbit, inclined 74°. The international geodetic community is participating in the observational program.

The second of the first generation active spacecraft, GEOS-B, is in preparation at the present time. The accomplishment of the gravimetric and geometric objectives of the program will also be continued, but they are expected to require additional satellites in a long range program.

In the 1968-1970 period studies will be undertaken to define in detail the missions to be performed by the Advanced Applications Geodetic Satellite of the long range program. Within this period, laser/radar altimeter techniques will be studied. An investigation may also be performed in the field of gravity gradient measurements. Geodetic accuracy and operational feasibility of laser tracking and of Airborne Ranging and Orbit Determination (AROD) will be investigated. The NASA spacecraft program in geodesy is summarized as follows:

Echo I – (1960)

Instrumentation	Application
Passive	Geodetic control

Echo II – (1964)

Instrumentation	Application
Passive	Geodetic control

GEOS I – (1965)

Instrumentation	Application
Corner reflectors	Range detection
Transmitter (162 and 324 Mc/s)	Gravity field studies
*Range transponder	Range determination
*Range rate transponder	Gravity field studies

PAGEOS – (1966)

Instrumentation	Application
Passive	World wide geometric network

Apollo Applications "AAP-B" (1970)

Instrumentation	Application
Metric camera system	Geodetic control
Mapping camera system	Cartography
Multi-spectral camera system	Earth resources
Laser/radar altimeter	Geoid determination

*No longer functioning

2.8 GEOMAGNETISM

2.8.1 Description of the Scientific Field Considered

Geomagnetism deals with the configuration of the magnetic field observed about the earth and with the changes it exhibits in response to environmental modifications occurring above and beneath the earth's surface. There is a long-standing and continuing demand for the best possible comprehensive, vector description of the close-in geomagnetic field. The motivation for examining the phenomena of geomagnetism has many facets, utilitarian as well as scientific. The disciplines concerned include sea and air navigation, exploration geophysics, the physics of the earth's interior, telecommunications technology, the study of trapped radiation, cosmic-ray investigations, space technology and the monitoring and forecasting of solar flares and other kinds of solar activity.

Present knowledge of the patterns of the geomagnetic field relies on the accrued results of observations made at some tens of thousands of observing points, distributed rather unevenly over the earth. They show that the field is roughly (but only roughly) equivalent to that of a short, strong bar magnet (or dipole) at or near the earth's center, with its axis not greatly different from the geographic axis. The actual field pattern departs from such an idealized dipole configuration in two principal ways. First, it exhibits large regional disparities (approaching a score in number) amounting to a substantial fraction of the main field vector, and affecting to some degree nearly every part of the globe. Second, it contains innumerable local departures or "anomalies" on a much smaller spatial scale, but some of them having a substantial effect and all of them potentially significant in the examination of the earth's crust.

Current needs call for a sustained program of surveys that must be repeated or in some manner updated at intervals of a few years, and for a description that is mathematically expressed and can be updated to take account of the secular change in the magnetic field. This necessitates analytically deriving a model from the available data (Hurwitz, et al, 1966).

Magnetic observations are currently obtained by ESSA, the Geological Survey, the U. S. Naval Oceanographic Office, and other agencies, using various techniques which include land, sea, and airborne operations. The land observations (including magnetic observatories) are essential for fine detail and for studying transient fluctuations and secular changes, but the uneven distribution of the earth's land masses is a severe handicap to this method of observation. Airborne and shipborne surveys are costly and have limitations of scope, particularly with regard to the complete vector description of the field. Airborne observations are playing a vital part in the current refinement of source data, as evidenced in the latest series of world magnetic charts (Heppner, 1965; Hurwitz et al, 1966).

All magnetic survey work must contend with serious contamination of the data by several kinds of noise, including spatial irregularities and complex transient fluctuations. The lowest altitude at which it is feasible to sustain a satellite would be well above the ionospheric E-region, so that for a close-in satellite-borne magnetometer, those transient effects which arise from E-region currents would be a contaminant opposite in sense but otherwise comparable to the corresponding ground phenomena. However, such "noise" could be minimized by appropriate selection of orbit and/or of data, to avoid the midday regions where the currents are most concentrated (Heppner, Stolarik, and Meredith, 1958; Davis, Stolarik and Heppner, 1965; Maynard, 1967).

2.8.2 Proposals and Related Requirements

2.8.2.1 Scope. Within limitations set by the noise problem, magnetic component surveys by satellites promise several advantages over conventional techniques. Coverage is rapid, comprehensive, and entirely independent of surface accessibility and sovereignty problems. The rapidity of coverage means that the epoch of the resulting model is well defined without invoking any secular-change corrections. Once the capability is established, new launchings can be scheduled for updating the model at intervals of a few years as needed. Secular-change analysis will be immensely enhanced if the currently well-covered regions (where magnetic observatories are situated) can be supplemented by repeated component coverage with satellites in the much larger areas where observatories are sparse or lacking. The satellite results also promise to yield a rich harvest of new knowledge bearing on the transient fluctuations and their synoptic features such as electrojets and coast-line effects, and on their analytic treatment and separation into internal and external constituents.

A considerable amount of satellite magnetic data has been obtained by NASA for the special purposes of space science (Heppner, 1965), and there has been at least one serious effort to map the global field (scalar total intensity) by satellite (Cain,

Langel, and Hendricks, 1966; Heppner, et al, 1967). There experiments have been conducted or are contemplated at various altitudes or planetary distances.

In order to derive a model for the geomagnetic field in the near-earth neighborhood, surface information combined with a relatively low altitude satellite mission yielding component data will be necessary.

In theory, component information can be derived indirectly from the analysis of scalar intensity, provided the scalar measurements are sufficiently accurate and well distributed over the globe. However, in different dip-angle environments, it is difficult to assess the extent to which the derived components are affected by noise in the scalar intensity.

Magnetometers thus far flown in satellites have been either scalar intensity sensors, or component sensors of a lower order of accuracy with relatively crude attitude control, in some cases restricted to the sensing of rapid fluctuations rather than absolute values. The Geological Survey is currently preparing an effort directed toward the study of long-wave crustal anomaly by means of satellite magnetometers.

2.8.2.2 Three Component Precision Magnetometer. To fulfill the requirements of ESSA in this discipline, a three-component assembly that can sense the vector field to gamma significance is needed. The sensor should be free from drift and accompanied with attitude and position control such that the overall uncertainties in mapping the vertical component of the field and its horizontal components in cardinal directions will be of the order of 1 to 5 gammas, including the error arising from position uncertainty.

With such an instrument flown in a circular, polar orbit it would be feasible to generate mathematical models and charts of the earth's field that would have decided advantages over those currently attainable. Planning should be coordinated so that there will be no duplication of development work.

Specific data requirements to fulfill the ESSA mission would be as follows:

a. The sensors (fluxgate or optical pumping principle) should measure three orthogonal components of field simultaneously, (that is, within a span of 200 milliseconds) with an accuracy of 1 to 2 gammas or better. All sensors should be mounted on a boom extended from the spacecraft.
b. The attitude of each sensor relative to a defined vertical and a defined horizontal direction should be specified to within 1 minute of arc at the time of each observation.
c. The spacecraft position at the instant of each reading should be known to within 1 km in latitude and longitude.
d. Area coverage should be world-wide up to at least 85° latitude, preferably up to 88°.
e. Data density should be of the order of six observations for each one-degree quadrangle – that is, say an observation for every twenty minutes of latitude and for every thirty minutes of longitude. With a polar orbital period of 1.5 hours, this would call for an observation every 5 seconds of time, with a total duration of 22 days. A 45-day program would confer a margin of extra data, permitting some selection of results for freedom from noise.
f. There would be no real-time requirement for data. However, onboard storage and telemetry capability must be sufficient to get all the data safely to ground stations, with a convenient choice of unloading epochs. Each sampling of the field would entail reporting up to 15 decimal digits of magnetic data and 22 of attitude and position data; this amounts to some 40,000 decimal digits of information for each orbit. These measurements should be carried out during periods of low magnetic activity.

There should be provision for comprehensive and intensive analysis of the data from different points of view, with a viable coordination of the interests of the agencies concerned and the scientific community in general.

2.8.2.3 Proposals for Future Consideration

A. Synchronous Satellite as a Magnetic Observatory

The two central problems which the science of geomagnetism has tried to solve are:

1. Origin of the earth's main field and of its secular changes, and
2. The mechanisms of the more rapid time variations.

In solid earth geophysics specifically, the difficulty of analyzing internal mechanisms is due not only to an ignorance of a specific model for the internal field, but also to the difficulty of separating magnetic fluctuations due to external and internal sources using only ground station data. Thus, despite the fact that for many years geophysicists have directed considerable effort towards resolving the

nature of the main geomagnetic field, major unsolved problems persist. In 1964, the Panel on Solid Earth Problems of the NAS/NRC summarized these problems in a series of ten questions (National Academy of Sciences, 1964b). Some of the problems were concerned with the origin of the earth's field, its time variations (especially those associated with solar activity), the relation of the field to the earth's rotation and the relation of the field to the continental drift.

Cross-correlating the measurements of magnetic fluctuations observed on a stationary satellite with those observed at ground stations would directly enhance the ability to separate the contributions which arise from current sources outside the earth from those due to magnetic fluctuations generated deep within the earth. Such measurements will involve observations of variations of the geomagnetic field for long periods of time, both at ground stations and on board the satellite. The time scales involved in some of these measurements will be on the order of a few years.

2.8.3 Related NASA Programs

NASA is currently involved in a Magnetic Field Program which has as its objectives:

- To survey the geomagnetic field in as detailed a manner as possible over the entire earth
- To investigate sources of electric current systems
- To study the character of the outer geomagnetic field
- To study the boundary regions of the earths magnetic field and the turbulent region immediately beyond this boundary

The geomagnetic field survey is to be repeated at no less than five-year intervals. Present plans for the US/USSR World Magnetic Survey call for polar orbiting satellites (POGO) to make measurements of the fields to an accuracy of better than ±5 gamma. These measurements would be made at an altitude of approximately 500 km at points spaced 10 km along a trajectory, with a minimum spacing between trajectories of about 400 km at the equator.

Electric current systems give rise to such ground-observed phenomena as diurnal magnetic variations, more pronounced variations caused by the equatorial electrojet, and magnetic storm changes, particularly the polar disturbances. Studies recently carried out near the equator indicate that the equatorial electrojet does exist. Further sounding rocket investigations of this jet is planned, in conjunction with electron density measurements.

Studies of the character of the outer magnetic field includes examining the rapid fluctuations which may be related to hydromagnetic waves in the exospheric plasma.

To date, much information about particle types, energies and densities out to roughly 60,000 km has already been acquired. As yet unanswered are basic questions about the trapping mechanism, possible acceleration of particles inside the magnetosphere, factors which control the trapping lifetime, and the mechanisms which produce sudden changes in particle population.

In seeking answers to these questions, investigations will be carried out along several lines. Multiple, simultaneous measurements will be required from several satellites to permit separation of temporal and spacial effects. A number of satellites are planned for launch almost simultaneously during certain aspects of the coming solar cycles, probably in 1972 during the period of declining solar activity, in 1975, near the solar medium, and in 1978 during the period of increasing activity. Some of these satellites would be in close proximity with almost identical orbits to investigate small scale irregularities and to detect phase coherent wave phenomena. Others will be widely spaced throughout the magnetosphere to permit reconstruction of the processes which occur when a solar wind shock front interacts with the magnetosphere.

Geomagnetic experiments are planned on several NASA spacecraft, including a combined EOGO-IMP, university and special purpose Explorer satellites, and multiple launches in which two or more small satellites would be placed in nearly identical orbits. Only the IMP experiments are defined here, however.

Interplanetary Monitoring Platform (IMP), E, F, and G (1967-1969)

Instrumentation	Application
Magnetometers	Magnetospheric and interplanetary vector magnetic fields.

2.9 SEISMOLOGY

2.9.1 Description of Scientific Field Considered

Seismology is the science concerned with earthquakes and attendant phenomena. Seismic waves, which propagate in the earth's interior, are recorded by seismography distributed over the earth's surface. From wave analysis, it is possible to infer the subsurface structure of the earth.

2.9.2 Satellite Data Requirements

Although seismology has a definite requirement for both large and small scale maps, this requirement falls under the discipline of geodesy, or it is a problem of topographic mapping. Frequent special mapping of seismically active areas, to a resolution capable of monitoring at least the major ground movements, would aid in assessing the surface manifestations of earthquake activity (see Section 2.9.3). High resolution photography could help solve the problem of assessing damage caused by earthquakes and similar catastrophic events. From an earth-orbiting satellite, fracture and tectonic pattern analysis of the broadest kind, by radar imagery, appears to be advantageous.

A special area of interest in the seismology program of ESSA is the Seismic Sea Wave Warning System (see Section 2.6.2.6, B and D). Rapid transmission of seismic data and tidal sensor data from widely distributed observation stations to the central analysis facility at Honolulu is presently accomplished utilizing submarine cables. It would be of interest to determine the technical feasibility and comparative costs of an alternate method of data transmission by relay from an orbiting satellite, possibly through a satellite in an earth synchronous orbit. In addition to the Seismic Sea Wave information, seismological data connected with fault monitoring systems, and other important areas of seismology could possibly be collected and relayed by satellites.

Since study of the earth's interior through seismic observations requires contact with the earth, there are only limited possibilities for using remote sensing for seismological purposes.

2.9.3 Related NASA Programs

NASA's program in Seismology includes the use of ground-based sensors, high-resolution photography, and radar and laser experiments to measure ground motion. Gradual movements of the ground would be measured by sensors on the ground. Instruments and techniques for transmitting data from these sensors to satellites is being developed as part of NASA's Applications Technology Satellite and Nimbus programs. High-resolution photography and radar/laser altimetry experiments are planned as part of the Apollo Applications (AAP) and Earth Resources Survey (ERS) satellite programs.

Motions of the ground are of two categories. The first includes slow creep such as continental drift and motions like those along the San Andreas Fault, estimated at 2 to 5 cm/yr. The second category is exemplified by abrupt displacements in excess of 10 meters, such as those associated with the 1964 Alaskan earthquake. Slow creep is best monitored on the ground, but satellite geodesy may still play a part. Thus far, such motions are known only relatively. If satellites could be used to determine the absolute motions along a fault – or, better yet, on a world-wide basis – our understanding of geodynamics would be vastly enhanced.

Motions along faults at the times of earthquakes could be monitored by a combination of satellite altimetry and photography. Data of this kind, particularly in the remote but earthquake-prone Andean and Himalayan Mountain regions, would shed new light on global stress patterns.

Specific experiments with applications to seismology are listed below.

Applications Technology Satellite ATS-C (1967)

Instrumentation	Application
Omega Position Location Experiment (OPLE)	Ground platform interrogation

Nimbus B (1968) and D (1970)

Instrumentation	Application
Interrogation, Recording and Location System (IRLS)	Ground platform interrogation

***Apollo Applications B and D**

Instrumentation	Application
Metric camera	High resolution photography
Panoramic camera	of fault areas
Ultra-high resolution camera	

***Earth Resources Survey (ERS)**

Instrumentation	Application
Metric camera	High resolution photography
Panoramic camera	of fault areas
Ultra-high resolution camera	

***Advanced Applications Geodetic Satellite**

Instrumentation	Application
Radar	Structural geology
Laser	Structural geology

***Proposed spacecraft.**

chapter 3
SYSTEMS CONSIDERATIONS

In the previous chapter a wide spectrum of future environmental satellite requirements was described and many selected proposals were discussed in detail. For future environmental services, the following additional factors must be considered: (1) instrumentation, (2) orbital requirements, (3) the data problem, (4) the role of man, (5) research and development vs. operational missions, and (6) observatory concept.

3.1 INSTRUMENTATION

Table 3.1-A lists the major instrument groups which satisfy the requirements described in Chapter 2. All figures are estimates and have order of magnitude value only. Several interesting facts become evident at once:

(a) Most instruments fulfill multidisciplinary requirements. Some are truly universal in character; e.g., optical systems (group 1) radar (group 4), and radiometric systems (group 5).

(b) Most instruments are either available or already under development. Among those requiring major development the radar scatterometer, the microwave imager, and the radio refractometer are of particular interest to the environmental sciences.

(c) The total weight, excluding power supplies, of all instruments listed in the Table 3.1-A adds up to approximately 5,000 pounds. Total volume depends on form factors but appears to be less than 500 ft^3. Accumulative power requirements are of the order of 5 KW. However, a meaningful instrument package for the environmental sciences will not require all sensors listed in Table 3.1-A; rather, it will consist of a selected group of compatible and complementary instruments. Furthermore, there is no need for simultaneous (accumulative) and continuous operation of all onboard instruments. On the other hand, redundancy would be required for eventual operational applications. Therefore, the total weight, volume and power requirements for environmental science spacecraft experiments can be estimated to be of the order of several thousand pounds, several hundred cubic feet and several kilowatts, well within the capability of SATURN-APOLLO class vehicles (see Table 1.3-B).

(d) There are a few instrument systems listed in Table 3.1-A whose weight, volume, and power requirements are of such magnitude that they probably can be placed only in SATURN-APOLLO class space vehicles.

Table 3.1-A – Space Instrumentation for Environmental Data

Instrument	Working Range	Application	Resolution Required	Recording Medium (See note a)	Availability (See note b)	Estimated			Discipline (Sec. or Table No.) (See note c)
						Vol. $ft.^3$	Wt. lbs.	Pwr. watts	
1. OPTICAL SYSTEMS									
(a) Line-Scan camera	4000-6000Å	Cloud characteristics	100m (horiz.)	MT,D	1	1	20	15	M(2.4.2.6) M(2.4.2.7) M(2.4.2.8)
		Ice & snow cover							M(2.4.2.5)
		Snow cover							H(2.5.2.2)
		River & Lake Ice							H(2.5.2.3)
		Shoal water							O(2.6.2.2)
		Sea Ice							O(2.6.2.5)
		Sea state							O(2.6.2.3)
		Water masses							O(2.6.2.4)
(b) Metric frame camera (multi-spectral, color, B&W)	4000-6000Å	Same as 1(a)	30m (horiz.)	F	3	70	1000 (see note e)	300	M,H,O
		Geodetic control for Cartography							G(2.7.2.2)
		Earth Surf. Prop.							A(2.3.2.5)
(c) Panoramic scanning camera (see note d)	4000-6000Å	Same as 1(a)	5m (horiz.)	F	3	60	500 (see note e)	600	O
		Cartography							G(2.7.2.2)
(d) Vidicon (41/2") or image/orthicon camera	4000-6000Å	Same as 1(a)	100m (horiz.)	MT	2	3	100	100	M,H,O
(e) Telescope	4000-6000Å	Weather Modif.	300m (horiz.)	F	3	15	200	–	M(2.4.2.6)
		Cloud Character	(@sync. alt.)						M(2.4.2.7)
(f) Refractometer, optical	4000-6000Å	Atmos. Density Profile	100m (vert.)	MT	3	5	150	70	M(2.4.2.2)
(g) Laser Ranging	6000Å	Orbital Height	3m (vert.)	MT	3	2	60	100	G(2.7.2.2)

NOTES:

a. F = Film
D = Direct (real time readout)
MT = Magnetic tape
n.a = Not applicable

b. 1 = Spacecraft hardware developed
2 = Not space qualified
3 = Requires additional development
4 = Needs major development

c. A = Aeronomy/Telecommunications
G = Geodesy
H = Hydrology
M = Meteorology
O = Oceanography/Hydrography
S = Space Environment
X = Geomagnetism

d. Laser used with panoramic camera.

e. Includes film

Table 3.1-A — Space Instrumentation for Environmental Data (Continued)

Instrument	Working Range	Application	Resolution Required	Recording Medium (See note a)	Availability (See note b)	Estimated			Discipline (Sec. or Table No.) (See note c)
						Vol. $ft.^3$	Wt. lbs.	Pwr. watts	
(g) Laser Ranging (Continued)		Cloud Top Height	200m (vert.)						M(2.4-A)
(h) Communication	4000-6000Å	Communications	n.a.	D	3	3	100	500	A(2.3.2.5)
(i) Polarimeter	3000-6000Å	Aerosol	n.a.	MT	2	5	25	30	M(2.4.2.10)
(j) Crossed Beam	to be determined		2m/sec	MT	4	to be determined			M(2.4.2.2)
2. PARTICLE COUNTERS									
(a) Solar proton monitor	0.1-60 Mev.	Proton Flux	n.a.	MT,D	1	1	5	5	S(2.2.2.2)
(b) Electron monitor	40 Mev.	Electron Flux	n.a.	MT,D	1	1	5	5	S(2.2.2.2)
3. PHOTOMETERS									
(a) Photometer	2500-4000Å	Ozone	n.a.	MT	3	1	30	5	A(2.3.1) M(2.4-A)
(b) X-ray photometer	0.5-60Å	Solar X-ray	n.a.	MT,D	3	1	15	1	S(2.2.2.2)
(c) Solar photometer	0.2-6μ	Solar constant	n.a.	MT	3	to be determined			M(2.4.2.10)
4. RADARS									
(a) Ranging	8.6mm	Orb. Height	±15m (vert.)	MT	2	3	60	60	G(2.7.2.2)
		Cloud Top Ht.							M(2.4-A)
(b) Images (vert. & side looking)	8.6mm	Precipitation	1 km (horiz.)	MT	3	15	200	500	M(2.4-A)
		Ice and Snow cover							M(2.4.2.5)
(c) Scatterometer	8.6-750mm	Surface roughness	1 km (horiz.)	MT	4	40	150	600	M(2.4.2.4)
		Sea state							O(2.6.2.3)
		Same as 1(a)							H
5. RADIOMETERS									
(a) Ultraviolet	2000-3400Å	Ozone	n.a.	MT	2	5	10	10	A(2.3.1) M(2.4.3)
		Solar flares							A(2.3.2.2)
		Solar flares							S(2.2.2.3)
(b) Solar spectrum	0.2-4μ	Albedo	0.5°K 200m (horiz.)	MT	2	3	25	15	M(2.4.2.10)

Table 3.1-A — Space Instrumentation for Environmental Data

Instrument	Working Range	Application	Resolution Required	Recording Medium (See note a)	Availability (See note b)	Estimated			Discipline (Sec. or Table No.) (See note c)
						Vol. $ft.^3$	Wt. lbs.	Pwr. watts	
(c) Infrared (incl. imaging)	10.5-12.5μ	Cloud top temp.		MT,F	3				M(2.4.2.2)
		Stratospheric Temp.							M(2.4.2.2)
		Water vapor							H(2.5.2.2)
		Snow cover							O(2.6.2.5)
		Sea ice cvr.							H(2.5.2.4)
		Temp. of River & lake water							
		Sea surf. temp							
5(d) Microwave	15-30mm	Surface Temp.	1°K 200m (horiz.)	MT,F	3				M(2.4.2.3) O(2.6.2.4E)
		River & lake ice distr.							H(2.5.2.3)
		Water mass diff.							O(2.6.2.4)
		Sea ice cover							O(2.6.2.5)
(1) Radiometer						1	15	15	
(2) Imager						10	150	50	
6. RADIO SYSTEMS									
(a) Electromagnetic Noise sensor	0.1-100 Mc/s 322-327 Mc/s	Electromagnetic interference	n.a.	MT	2	10	150	300	A(2.3.2.4)
(b) Sferics detector	Wideband	Atmos. electricity	n.a.	MT	2	2	30	10	M(2.4.2.9) A(2.3.2.4)
(c) Radio frequency refractometer	10 Gc/s	Vert. Atmos. Density profile	30m (vert.)	MT	4	10	300	100	M(2.4.2.2A)
(d) Ionosonde	0.1-30 Mc/s	Electron flux	n.a.	MT	3	10	300	300	A(2.3.2.3)
(e) Interrogation & relay	137 Mc/s	Envir. Data (grnd. and airborne)	n.a.	MT,D	1	1	5	100	M(2.4-A) M(2.4.2.2C) H(2.5.2.5) O(2.6.2.7)
7. SPECTROMETERS									
(a) Ultraviolet	2500 3400Å	Vert. sounding (ozone, atmos. temperature, water vapor)	1°K	MT	2	2	100	50	A(2.3-1) M(2.4-A) M(2.4.2.2B)
(b) Infrared	11-40μ			MT	1	2	50	50	
(c) Interferometer	5-20μ			MT	1	2	30	10	
(d) Microwave	.3-3mm			MT	2	10	100	50	
(e) Mass spectrometer	1-45	Ion composition	0.5-20 amu	MT	2	5	200	25	A(2.3.2.2)
8. GEOPHYSICAL SENSORS									
(a) Magnetometer	n.a.	Magnetic field	$\pm 1\gamma$	MT	3	10	50	15	X(2.8.2.2)
		Ionospheric currents	$\pm 1\gamma$	MT	3	10	50	15	A(2.3.2.2)
(b) Gravity gradiometer	n.a.	Gravity gradient	$\pm 5 \times 10^{-11}$ gal/cm	MT	4	5	50		G(2.7.2.1)

3.2 ORBITAL REQUIREMENTS

3.2.1 Preferred Orbits

The majority of space programs proposed for the environmental sciences require global coverage and therefore, a space platform in a *polar orbit.* In many, but not all cases, the orbit should also be sun-synchronous.

There are opposing requirements for coverage and resolution. To assure sufficient swath width for global coverage orbital heights in excess of 700 miles should be selected. To achieve maximum resolution, the lowest orbits compatible with mission durations are desirable (200 miles). For operational purposes, the global coverage is generally overriding and imposes a serious limitation on the use of manned spacecraft in view of the radiation hazards. Therefore, unmanned satellites will be a continuing requirement. Where manned spacecraft are mandatory, they should be placed in orbit at the maximum safe height under the Van Allen belts.

Features of interest in the earth sciences are generally quasi-permanent (secular changes) and do not require daily global coverage. Every point on earth can be covered over a period of a few days by a spacecraft in polar orbit if the altitude used is such that orbital passes do not occur over the same equatorial longitudes on successive days. Thus, low orbits are admissible and actually desirable for optimum resolution.

For rapidly changing phenomena, such as atmospheric convective systems, squall lines, hurricanes and weather modification experiments, continuous observation from *synchronous* (geo-stationary) orbit is needed. This type of orbit is the superior choice if the continuity of cloud systems or the motion and time changes of individual clouds are studied. Already the scan camera of the first ATS satellite presently in synchronous orbit permits us to determine cloud movements within 5 knot accuracy using successive frames at about 20 minute intervals (see 2.4.2.2). Improvements in resolution and spectral range anticipated for future synchronous spacecraft offer unprecedented possibilities for all environmental disciplines. While geo-stationary observing platforms properly spaced around the globe deserve the highest priority, certain experiments are difficult to perform from this height (atmospheric temperature and density soundings, sea state meas-

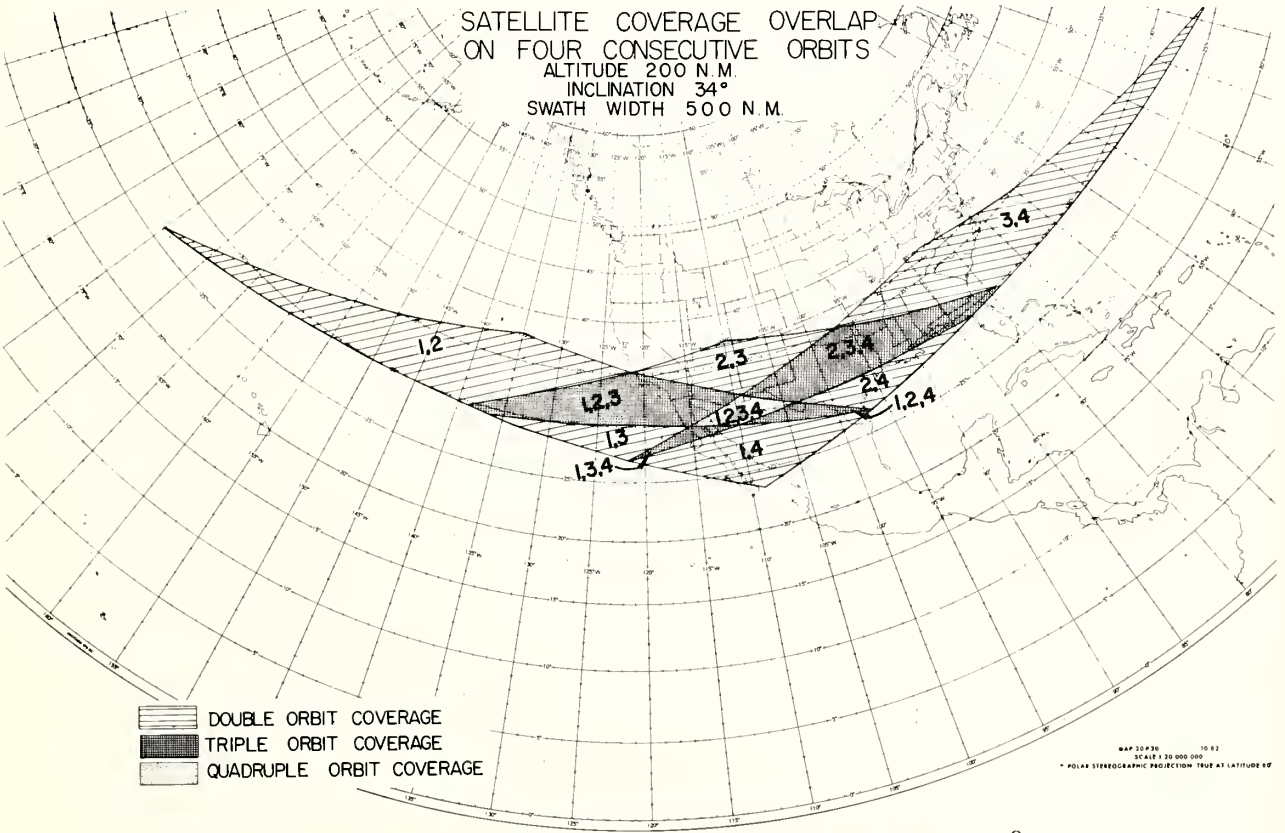


Figure 3.2-1. Overlap of earth coverage areas for four consecutive satellite orbits. (34° inclination).

urements, etc.). The merits of nonequatorial synchronous orbits also need to be analyzed, as continuous observation may be traded off for increased coverage. For example, synchronous orbits with 45° inclination offer continuous observation of the order of 6 hours over very large areas.

At this time, it can be stated that both polar and synchronous orbits will be needed for environmental science services.

3.2.2 Orbital Overlap

A special study was made to explore the possibilities for low orbiting manned observatories to view the same location on several consecutive passes from non-polar orbits. This question is of interest not only for repeated observations of rapidly changing geophysical phenomena, but also for cases in which an interesting feature has been missed on the first pass and a second chance is sought. (From a 200 mile orbit, any point within a 500 mile wide swath can be viewed only for 100 seconds or less.

Obviously in the two extreme cases of a polar orbit and a non-synchronous equatorial orbit, the polar caps and the equatorial belt respectively, will be traversed on each pass, i.e., every 1½ hours. For

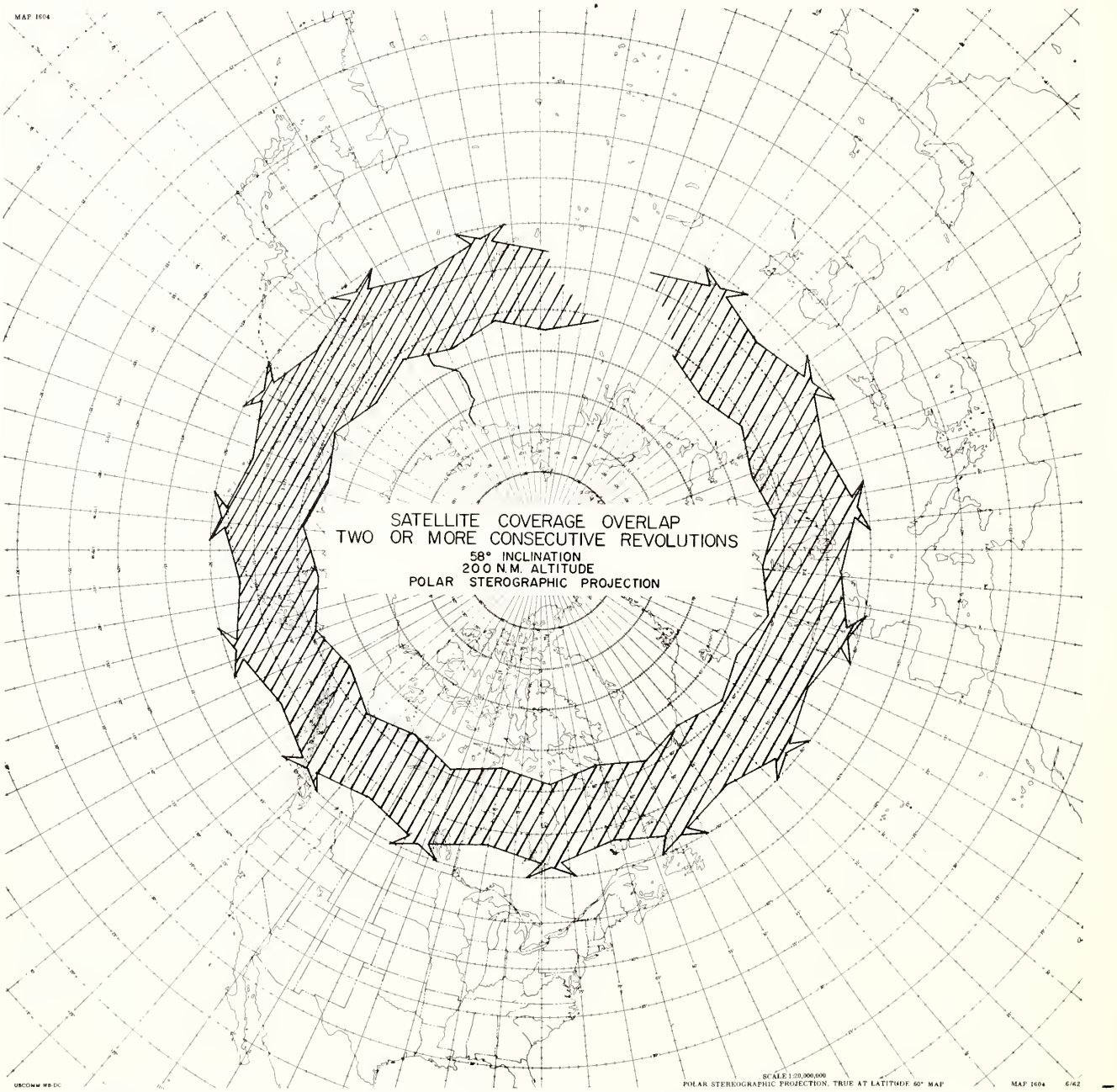


Figure 3.2-2. Overlap of earth coverage areas for two or more consecutive satellite orbits. (58° inclination).

intermediate inclinations, the overlap coverage of 4 consecutive orbits show a characteristic pattern concentrated at the inclination latitude (as shown in Figure 3.2-1 for 34° inclination). If followed around the world, a belt about 10° wide is found in which every location can be viewed twice on successive orbits (see Figure 3.2-2 for 58° latitude). Within this belt a pattern roughly 5° wide permits 3 to 4 consecutive observations (Figure 3.2-3). At middle latitudes, these belts amount to less than 10 percent of the earth's surface.

The opportunity for repeated viewing, moderate though it may be, is of interest for non-polar orbits with manned spacecraft. We will come back to this point when the "Role of Man" (Section 3.4) is discussed.

3.3 THE DATA PROBLEM

3.3.1 Present-Day Data Handling

The latest operational weather satellite (ESSA 3) uses an Advanced Vidicon Camera System (AVCS) with a viewing angle of 89° and 800 scan lines per picture. Twelve TV pictures of the illuminated half of the earth are transmitted, on each orbit, to

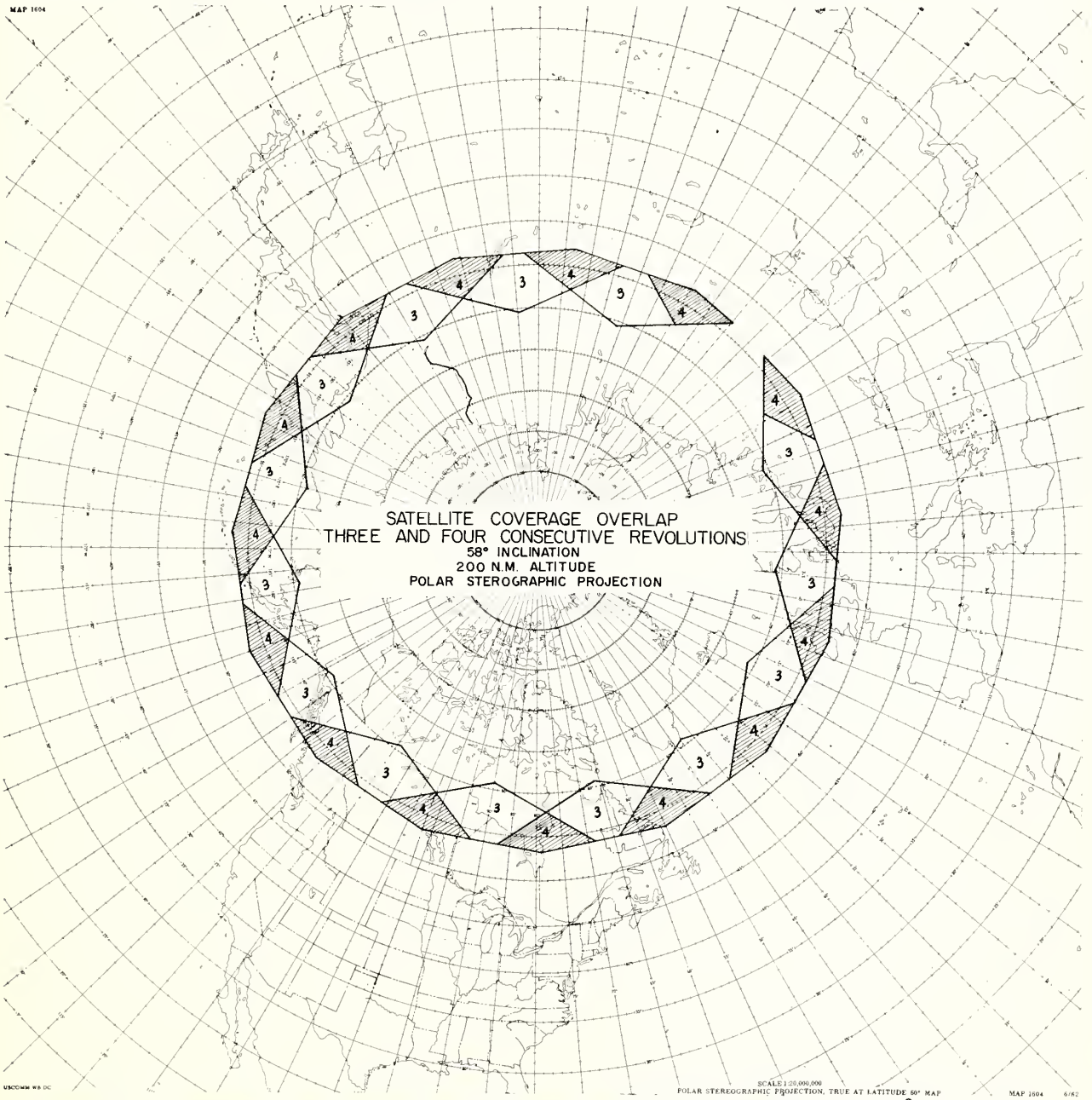


Figure 3.2-3. Overlap of earth coverage areas for three and four consecutive satellite orbits. (58° inclination).

Figure 3.3-1. A polar stereographic "montage" of rectified, gridded digital video data received from ESSA 3 showing cloud distribution over the Southern Hemisphere on November 16, 1966.

ground based Command and Data Acquisition Stations (CDA-Wallops Island, Va. and/or Gilmore, Alaska). The video data is forwarded from the CDA stations via ground microwave links (16 Kc/s Bandwidth Channel) to the Data Processing and Analysis Facility (DAPAF) in Suitland, Maryland, where a worldwide rectified and gridded cloud montage is produced daily.

The initial step at DAPAF is the digitizing and formatting of the analog video data for follow-on digital computer processing. The digitized pictures from each orbit are rectified, gridded in longitude/latitude (using recently-obtained satellite attitude information) and then matched to form a "mosaic" of each orbital swath. Each mosaic is subsequently matched with its adjacent orbital mosaic to form a global picture ("montage") of the earth's cloud cover with a resolution of approximately two miles (see Figs. 3.3-1, 2). Illumination corrections are performed to eliminate brightness anomalies due to solar angle, optical systems, etc. (Bristor, et. al., 1966).

The data processing is performed utilizing a large storage, high speed (CDC 6600) computer. Many software packages are employed and presently require more than 50% of the computer's useful time. It is anticipated that as more software packages (computer programs) are developed and utilized, the computer time requirement will soon increase to 100%.

3.3.2 Future Data Handling

Considering the vast volume of data that will become available from future space platforms, careful planning is required to achieve data processing on a timely basis. System analysis, computer programming, software checkout, debugging and establishment of operational procedures are tasks requiring long lead times, highly skilled personnel, and top-of-the-line hardware (computers, displays, input/output, communication links).

Table 3.3-A gives an example of the volume of data to be expected from a spacecraft such as that proposed for earth-oriented applications. Five high resolution imagers such as scanning cameras are assumed.

Table 3.3-A — Typical Expected Data Volume

Horizontal Resolution	100 Meters
Swath Width	800 Kilometers
Data Points Per Orbit	3×10^9 per device
Dynamic Resolution	6 Binary Bits/Data Point
Total Data Volume Per Orbit	10^{11} Binary Bits

If all the data per orbit were to be dumped over one receiving station, the bandwidth required would be over 500 Mc/s. The utilization of a synchronous communications satellite continuously transmitting data to ground stations would reduce the bandwidth from 500 to 3 Mc/s. Considering the power supply available, no serious problems should be anticipated in transmission of data to the ground. However, reduction, data processing and the output of meaningful information via displays or hard copy would still be beyond the capability of present or near future hardware.

The latest digital display devices in use can handle at best 500,000 bits per second in real time with maximum picture resolution of 2000 x 2000 data points. Internal memory cycle time of the fastest

Figure 3.3-2. A mercator "montage" of rectified, gridded digital video data received from ESSA 3 showing cloud distribution over the entire equatorial belt on November 16, 1966.

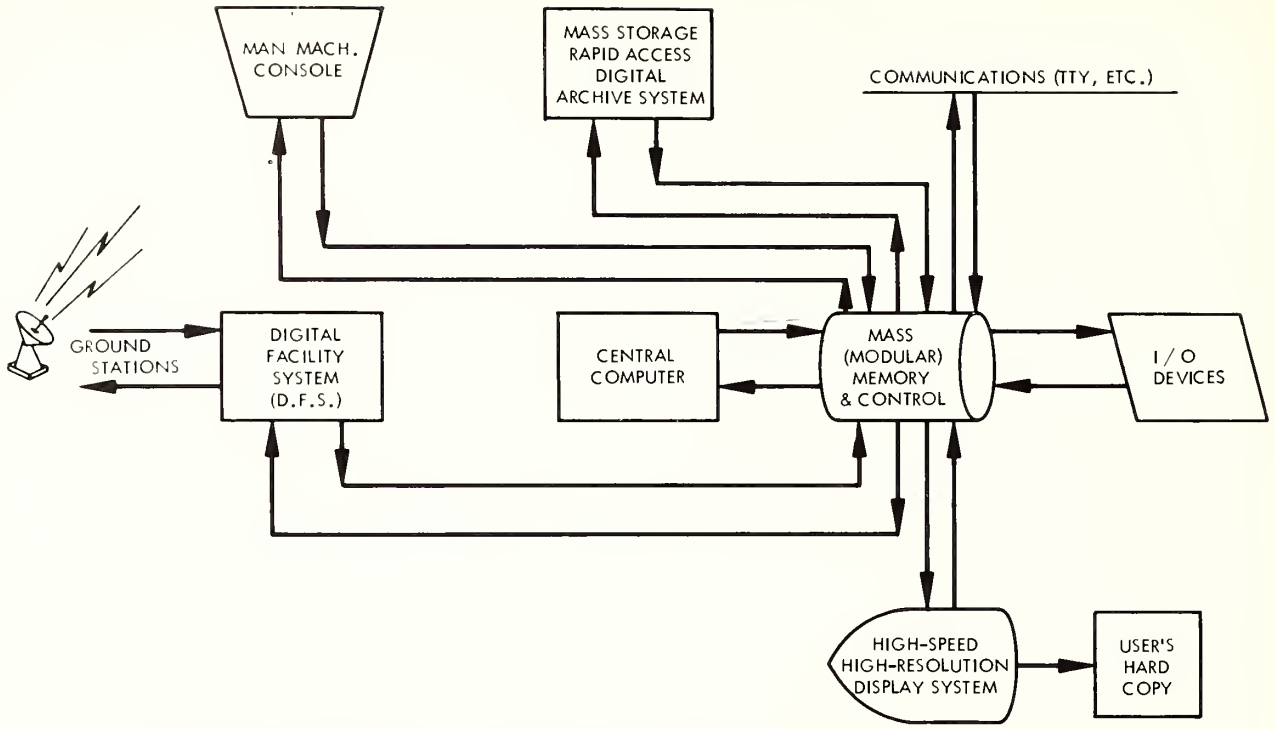


Figure 3.3-3. Block diagram of a typical computer controlled system for satellite data handling.

computers is approximately 0.1 micro-second per 60 bit word, but overall efficiency greatly depends on software support, operational programs and linkage speeds of input/output devices (tapes, disks, etc.). The fastest rate of present-day magnetic tapes is less than 2 million bits per second. Therefore, it appears that operational data utilization would run into bottlenecks at the computer interfaces and the display hardware.

To obtain maximum usefulness from the total data available (realizing above mentioned limitations) an early data selection process should be performed onboard the spacecraft. While it is desirable to rely on fully automatic pre-programmed devices, an onboard scientific observer/operator would be most valuable in the real time selection of live data since it is extremely difficult to program for all eventualities. An additional problem exists concerning the recovery of physical data (photographic films, samples, etc.) which are to be analyzed on the ground with a minimum of delay. Special re-entry vehicles to be launched by the crew from manned observatories for recovery at appropriate times and locations will be required and should be planned for as early as possible.

To make full operational use of the field of view and the resolution available for observations from synchronous orbit (order of magnitude 10,000 lines), near-real-time, time-lapse displays will be required which permit the operational observer to zoom at selected targets with full resolution to observe their development repeatedly. Examples for such targets are fronts, squall lines, hurricanes, typhoons, weather modifications, and damage from earthquakes and storm surges.

Industry is continually striving to meet the challenge of ever increasing demands for faster and larger storage devices. It is encouraging that major breakthroughs and technological advances appear to be forthcoming in the near future. Computers are being designed to provide larger and faster memories. Archival devices presently in the prototype stage will be capable of transfer rates in excess of 10 megacycles while reducing storage space requirements by a factor of 50,000. Laser and fiber optic techniques are being developed for display devices increasing resolution to beyond 6,000 lines for a five inch film.

Figure 3.3-3 is a general block diagram of a possible operational computer complex that would utilize top-of-the-line hardware to facilitate the data problem.

Assuming that the major technological problems of data handling are soon to be overcome, a final problem exists in the interpretation and analysis of these data in order to obtain a maximum of meaningful results. Either sufficient, high quality human

resources are required, or objective techniques must be developed in automatic processing, utilizing high speed, high data storage computer systems that would reduce the manual effort. Many processes, involving human judgement in recognizing synoptic data patterns, show promise for computer applications. These techniques and others should be thoroughly investigated and perfected in order to increase operational efficiency and facilitate the production of useful end products.

Summarizing, we may state that the main data problem lies not in the spacecraft but on the ground. Also, the "data explosion" problem must be faced realistically today. Therefore, development efforts for software and data handling equipment on the ground must match the development efforts in space technology, both in time and resources, if full user benefits are to be obtained.

3.4 THE ROLE OF MAN

Much of the existing dispute about man's role in space boils down to a subjective judgment regarding the degree of technical sophistication which may be required and justified to replace his functions by automatic or ground-controlled systems and to match his flexibility.

If, for example, a proton counter needs to be switched on and off at a given time, the required sophistication of an automatic system is insignificant. If, on the other hand, atmospheric discharges of unusual length are to be observed and photographed from orbit during the night, the complexity of a properly-programmed automatic system may be excessive. If a mechanical component needs to be repaired or replaced, the required sophistication would almost certainly be prohibitive.

3.4.1 Potential Crew Functions

Assuming that a laboratory or observatory type spacecraft is on a scientific or engineering mission and carries special equipment to observe natural phenomena, the function of the astronaut crew can be equipment-oriented, phenomena-oriented or flight-oriented.

A. Equipment-oriented Functions

Referring to experiment equipment rather than basic vehicle equipment, the operation, calibration or deployment of instrumentation systems should be distinguished from maintenance, repair, and assembly activities. Operation of a radar scatterometer for sea state, calibration of a radiometer for surface temperatures, pointing of a telescope toward a target of opportunity, and deployment of an unmanned slave satellite for refraction measurements, are typical *operator* functions.

Maintenance of a radar imager for precipitation, repair of a tape recorder, retrieval and replacement of a vidicon camera from an unmanned satellite, or assembly of an antenna array, are typical *service* functions.

Thus, the equipment-oriented functions of the astronaut are either operator or service functions.

B. Phenomena-oriented Functions

Turning to objects for observation, astronaut activities include the selection, observation and description of natural phenomena (programmed or unexpected), and two-way communications and cooperation with the ground. Large scale weather modification experiments and selective data collection or transmission are examples of this function.

Table 3.4-A — Role of Man in Scientific Space Operations

FUNCTION	ORIENTATION
Service Function	Equipment-oriented
Operator Function	Equipment-Oriented
Observer Function	Phenomena-Oriented
Pilot Function	Flight-Oriented
USEFULNESS	**CHOICE OF SPACECRAFT**
Man Essential or Desirable	Manned
"Useful but not Necessary" (not essential)	Manned or Unmanned
Undesirable or Unacceptable	Unmanned

In performing activities of this kind the astronaut is primarily a scientific *observer.*

C. Flight-oriented Functions

In his most familiar function, the astronaut is not only concerned with the normal flight control of the vehicle, but with the support of special scientific missions which require pointing and maneuvering of the spacecraft and extra-vehicular activities for recovery of samples, films, etc. This we call his *pilot* function.

Thus, we arrive at the functional scheme of Table 3.4-A (upper part) for the role of the astronaut in scientific operations. The operator and observer functions are more nearly related than are the other crew functions.

3.4.2 How Essential is Man

It is not the purpose of this report to enter the widespread argument about manned vs. unmanned spacecraft. A manned space platform should at most supplement, not replace unmanned spacecraft. In our opinion, it is not only a matter of technical, economical and program analysis, but also a matter of national decision to what extent the achieved manned spaceflight capability will be applied to user-oriented programs.

In studying the utilization of space platforms for the environmental sciences, we have tried to arrive at certain qualitative conclusions regarding the significance of man's participation in the experiments. It was recognized early in the study that the answer is different for different experiments or groups of experiments. Therefore, the extent to which the success of each proposed experiment would depend on crew participation was considered. Such considerations require qualitative judgments regarding the degree of sophistication required in an automatic system which would be needed to replace human functions. Consideration has also been given to the possible interference of man or manned systems with scientific experiments.

While the choice of a manned or unmanned vehicle depends on many factors such as weight, power requirements, life time, cost, etc., the role of man is an important contributing factor in this decision. The lower part of table 3.4-A lists our terminology in regard to man's usefulness and the corresponding choice of spacecraft. On this basis, an attempt has been made to give relative ranking to the potential crew functions. In our opinion, the ranking coincides with the order in which the functions are listed in table 3.4-A.

The *service* function is expected to be of increasing importance in the future. This is not only true for the onboard instrumentation, but also for the maintenance, retrieval and repair of malfunctioning unmanned satellites. It also implies that attention should be given to modular design of unmanned spacecraft such as weather satellites in order to facilitate the replacement of subsystems. (An example is the recent failure of a vidicon camera on the ESSA 1 satellite which interrupted important worldwide operations.) In synchronous orbit, a colony of unmanned satellites could be served from a central service station. Satellites flying in polar orbits at levels between 500 and 1,000 n.m. could be retrieved for maintenance and repair at lower levels without requiring more than transitory exposure of the crew to radiation. We rank this function highest because the sophistication of an automatic system to perform such activities appears prohibitively high and the need for such a system has been demonstrated all too often. Figure 3.4-1 illustrates how an unmanned Nimbus weather satellite might be serviced from a manned Apollo type laboratory.

The *operator* function is likewise ranked high for space platforms with complex multiple sensor systems. For certain targets, such as a newly discovered hurricane in the formative stage, high resolution measurements are needed of sea temperature, sea state, cloud structure, cloud height, and the vertical and horizontal distribution of temperature, water vapor, and wind. From a satellite in a polar orbit all these measurements must be made simultaneously and the sensors must be properly pointed during a very short path over the target area, since there is little chance of a "second look" during a subsequent orbit (see section 3.2 above). For this type of measurement, before and after calibrations are also important.

Furthermore, we see increasing significance in the launching or deployment of unmanned special purpose satellites from a manned spacecraft. Several examples are given in Chapter 2. Among the advantages of this technique are: proper positioning of the satellites in orbit with respect to the manned spacecraft (e.g. radio occultation experiment); careful checkout and adjustment of highly sensitive equipment prior to ejection (e.g. gravity gradiometer satellite); proper outgassing by vacuum soak as well as deployment at a location of choice (e.g. mass spectrometer/descending satellite experiment), and independence from special launch vehicles.

Finally, thorough testing of instrumentation, under actual space conditions, for research and development purposes and for later use in unmanned satellites should be most valuable, especially since the size of manned spacecraft and its available power would not require miniaturization of prototype equipment.

On the other hand, there are many non-complex experiments which can operate automatically and do not require a crew member for operation. The majority of these proposed experiments require continuous long term monitoring and fall under the category "Man useful, but not necessary" (Table 3.4-A), leaving the choice of manned or unmanned vehicles to other considerations.

In some cases, the presence of a crew is undesirable or unacceptable. Examples are experiments onboard spacecraft in orbits passing regularly through the radiation belts or experiments directed toward the recording of high energy solar protons, etc. Also the presence of certain systems for life support, such as radiation type tank gauges, may interfere with specific experiments.

We rank next the *observer* function which is somewhat difficult to assess at this time. Once a manned mission has been flown for the primary purpose of scientific observation, the role of the scientific observer will become clearer. Some of the questions entering an assessment of the situation are listed here:

(a) Can the results of man's total range of perception be transmitted to the ground and displayed in such a manner that they can be analyzed in real time by a more competent and specialized ground team?

(b) Is immediate decision-making important and does this decision have to be made by the flight crew?

(c) Is the situation different for low and for synchronous orbits?

(d) Are unexpected situations, including the discovery of rare natural phenomena, a major factor?

(e) How important is scientific two-way communication between an onboard observer

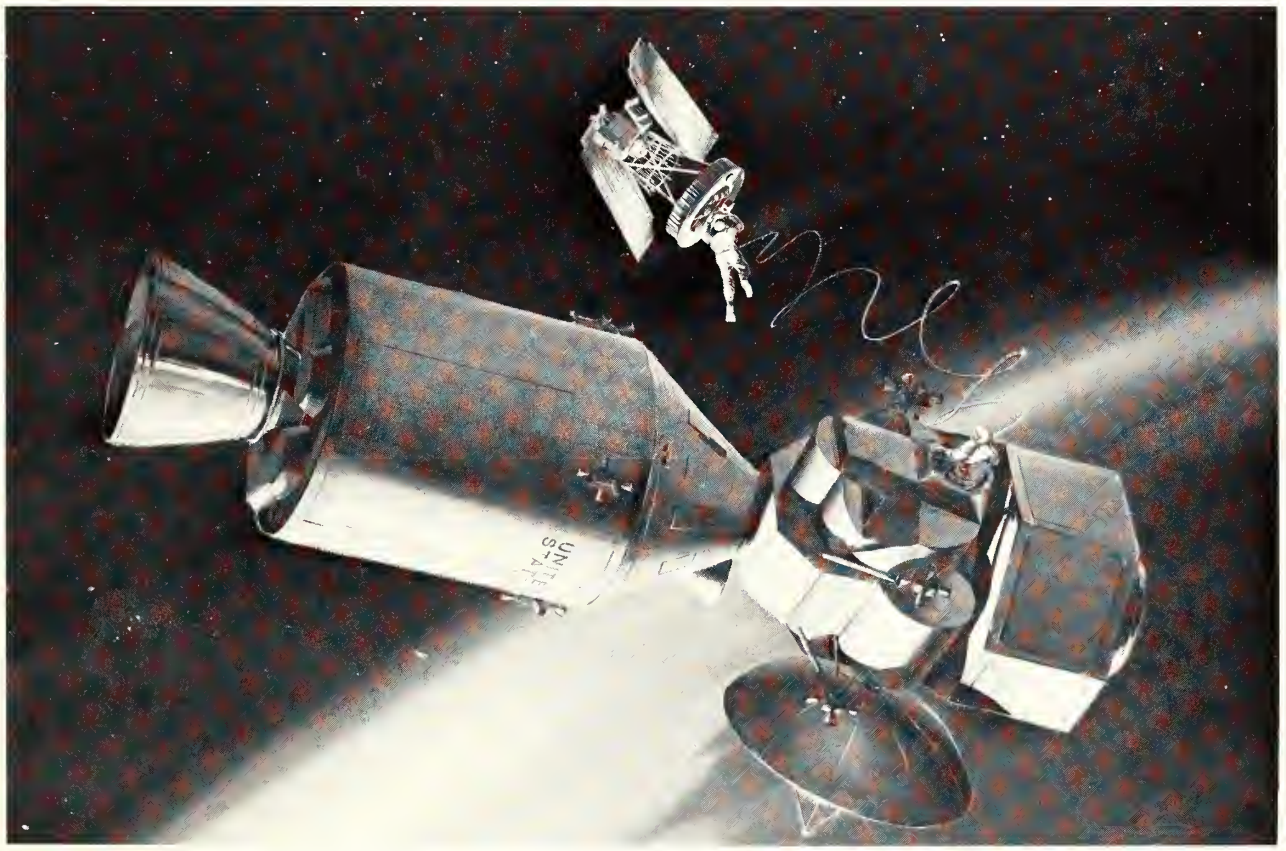


Figure 3.4-1. Service function of flight crew. In this artist's concept an astronaut performs maintenance work on an unmanned meteorological satellite (Nimbus) while connected to his orbiting base, an Apollo type space platform. (Photo courtesy NASA).

and a field crew on the ground? To what extent can it be done?

(f) How important is selective data collection and transmission by the flight crew?

(g) Is man as an onboard sensor system superior to an array of automatic sensors and in what respect?

(h) Does he need vast real time displays onboard?

It appears that most of these questions are not only difficult to answer but cannot be answered in general terms at this time. There are, however, pieces of information available which affect the answers to some of these questions.

For example, a look at the data handling problem given in section 3.3 suggests that the answer to question a is "no," and will be so for some time to come.

In regard to question b we take the case of a 200 mile non-polar orbit. For features near the earth's surface to be viewed at angles of 45° or less from the vertical only about 100 seconds are available on one pass. Therefore, a decision to use complex equipment has to be made and executed immediately, or a "second look" has to be scheduled for the next opportunity, provided there is one. There is reason to doubt that this kind of instantaneous action can be taken except by an onboard observer, unless the total instrumentation is running continuously.

If the flight crew has missed the first opportunity or if the ground crew, after proper evaluation of the available data, decides to act at the next pass, chances are that no consecutive orbits will pass over the same location. As described in section 3.2 (fig. 3.2-1 to 3.2-3), only very specific areas, amounting to a small fraction of the earth's surface, are covered two or more times on subsequent orbits. For rapidly changing features, such as convective system with a lifetime of a few hours, or those with strong diurnal variation, the crew has to take immediate action and the answer to question b appears to be "yes."

In a synchronous orbit, this problem does not arise and in this respect, the answer to question c is also "yes." However, the synchronous orbit cannot replace the low orbit, for certain measurements such as vertical soundings (see section 3.2).

In regard to question d, the case for the "unexpected" has often been quoted and is indisputable. It is also very difficult to predict its significance since the unexpected cannot be predicted, only prepared for. This, however, must be done whenever possible.

Two-way communication (question e) between onboard and ground scientists is promising, provided present communication procedures are modified to permit direct voice communication with the scientists in the field. An example of such cooperation in large scale weather modification experiments is discussed in section 2.4.

A significant role of a scientific observer may be selective data collection and transmission (question f) as suggested in section 3.3 on the data handling problem. Very good scientific and operational judgment would be required.

Questions g & h will have to await some systematic flight tests. Man's visual capability and experience in respect to orientation and observation may be his greatest asset (Kondratyev, 1966).

In summary, the case for the astronaut as a scientific observer is not as straightforward at this time as his equipment-oriented functions and has, therefore, been ranked lower. This, however, is primarily due to a lack of scientific spaceflight experience. The future may prove this to become a very significant crew function provided the right crew member is selected. It appears that a carefully designed manned flight mission for the primary purpose of scientific observation will supply this answer.

The National Academy of Sciences and the National Research Council view the observer function of the scientist as an astronaut highly, and define it as follows (National Academy of Sciences, 1966a):

"The task requires an exceptionally astute and imaginative observer but also one whose observations are accurate and impartial. He must, from among the thousands of items he might observe, quickly pick out those that are significant, spot the anomalies, and investigate them. He must discriminate fine detail and subtle differences in unfamiliar situations, synthesize observations to gain insight into a general pattern, and select and devise key observations to test working hypotheses. He must have the good judgment to know when to stop a particular set of observations and turn to the next.

The scientist as an astronaut must translate observations into verbal form and be able to generalize from observations to derive appropriate conclusions."

In order to take full advantage of these possibilities we would like to see a professional geophysicist with laboratory experience onboard. It is not just a matter of training and briefing but primarily one of scientific interest that will motivate an astronaut to exploit fully the opportunities of an orbiting obser-

Table 3.4-B – Primary Applications of Manned and Unmanned Spacecraft

MANNED	UNMANNED
Coverage:	Coverage:
Short term	Long term
Near global	Global
Selected areas	
Orbits	Orbits
Low, polar	Free choice
Synchronous	
Experiments	Experiments
Heavy/large	Light/small
High power	Low power
Research	Operational
Dev. testing	Continuous monitoring
Data	Data
Selected transmission	Stored
Recovery	Real time transmission
Crew participation	
Service function	
Operator function	
Observer function	
Pilot function	

vatory. Thorough training at ESSA's varied facilities is highly recommended.

Little will be said here for the *pilot* function of the astronaut since this activity has passed the discussion stage. The support the astronaut can give to a scientific mission in this respect lies primarily in his maneuvering skill and the ability to apply extra-vehicular activity to special tasks, such as the recovery of experiments.

Summarizing our conclusions, we find a great number of our proposed experiments in a class where manned *or* unmanned spacecraft can be used, i.e., where man is "useful, but not essential." There is a limited number of experiments in which man's participation is essential, and another limited group where he is unacceptable. In general, the functions the astronaut can perform are so varied that it must be considered an advantage to have him onboard. This conclusion by no means implies that unmanned operational satellites do not have a solid place in the environmental science program. Taking other factors into account, such as payload capability and flight duration, the primary applications of manned and unmanned space platforms evolve as given in Table 3.4-B.

3.4.3 The Telefactor Concept

An interesting concept which should be mentioned here is the "Telefactor" (Bradley, 1967). The Telefactor comprises a mobile master-slave manipulator together with a two-way telemetry system and a one-way television channel from satellite to ground. A Telefactor, in theory, can grasp and move objects, exert controlled forces in prescribed directions and locations, can minutely observe exposed portions of the remote environment, can do combinations of these actions, and can perform a much greater variety of tasks that can be done by special purpose control equipment. By the Telefactor, man can sense in his fingers, hands, and eyes the reactions felt and seen remotely by the machine with the additional possibility that the actual forces involved may be amplifications or attenuations of the physical characteristics of a human being. Environmental control and life support requirements (food, air, radiation shields, etc.) can be eliminated or modified by replacing man with a machine system. Another advantage of a Telefactor is the ability to withstand greater accelerations. Finally, a miniaturized mechanical man with certain human functions could be

placed in small satellites and controlled from the ground.

If the Telefactor should be developed and perfected it may be kept in mind for smaller spinning satellites or for scientific platforms in orbits which are presently prohibited for human crews. While the total perception and flexibility of an astronaut crew is unlikely ever to be replaced by this type of device, the Telefactor may approximate certain operator and observer functions if geophysical phenomena require realtime action.

3.5 EVOLUTION FROM R&D TO OPERATIONAL MISSIONS

The usual distinction between R&D and operational flight missions or activities is useful but not as straight forward as generally assumed. In practical terms one needs to distinguish the following phases:

(a) Engineering development and testing of instrumentation and related systems.
(b) Data collection for research purposes.
(c) Preoperational research and testing.
(d) Data collection for operational purposes.

It should be recognized that all four aspects can overlap in the same mission or vehicle.

An original attempt to separate the environmental science requirements into research and operations was soon abandoned when it became apparent that the majority of operational requirements had their counterparts in research. Information on sea ice, for example, is of operational value to navigation and of scientific value to oceanography and meteorology.

Where the distinction becomes significant is in the regularity of the data collection and in the real time requirements for data handling and dissemination. Obviously, reliability (implying simplicity and redundancy) is the over-riding consideration for operational systems while for research, requirements are more flexible. In cases where operational spacecraft malfunction, research spacecraft will have to fill the gap provided data collection and reduction procedures have been properly preplanned. (ESSA has tried to do this with TIROS 9 and Nimbus data after the failure of the ESSA 1 satellite.) Thus, the same mission may serve (b) and (d).

Developmental testing of instrumentation on board a spacecraft can likewise serve several purposes: to test a new instrument concept, or to perfect an operational prototype. If tests yield observational data of a new kind, they are almost invariably of high scientific value. In these cases the development tests may serve (a), (b), and (c).

Phase (c) ("Preoperational research and testing") has been listed here because it is a gray area and easily overlooked. It is neither pure "R&D" nor "operational," but an in-between phase and of particular importance to operational vehicles, because it is not possible to jump directly from research and development into operations. A data collection phase is necessary to test, under actual space flight conditions, optimum data collection and transmission methods, streamlined real time data processing, and optimum data application at the user's end. With increasing complexity of future space observatories this preoperational phase will grow in importance. The evolution of R&D to operational vehicles is a gradual one.

3.6 OBSERVATORY CONCEPT

For unmanned satellites there is always a question of whether it is more economical to use larger vehicles carrying many experiments, or a number of smaller vehicles, each carrying a single or a few experiments. When continuous or operational data are required the problem is particularly vexing, since the necessity to repeat launches adds greatly to program costs.

If the experiments are unrelated, the preference of an individual experimenter generally is for the single purpose satellite provided this is economically possible. If the multi-purpose satellite gives him an earlier or perhaps the only chance to fly his experiment he will accept certain compromise and priority problems connected with this type of spacecraft. Per pound of payload the larger vehicle is generally more economical.

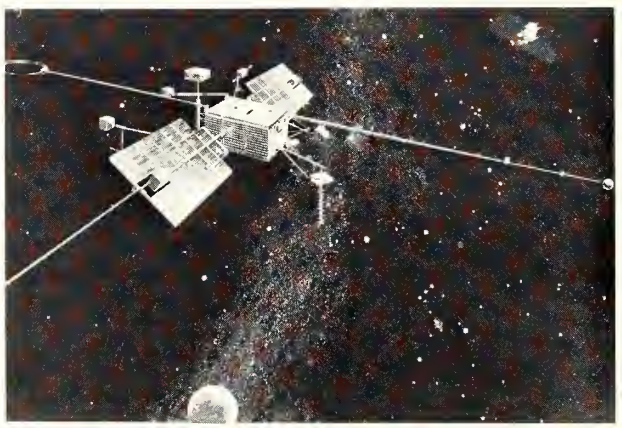


Figure 3.6-1. OGO (Orbiting Geophysical Observatory), an example of a multi-purpose observatory spacecraft carrying approximately 20 experiments covering a wide range of geophysical problems. (Photo courtesy NASA).

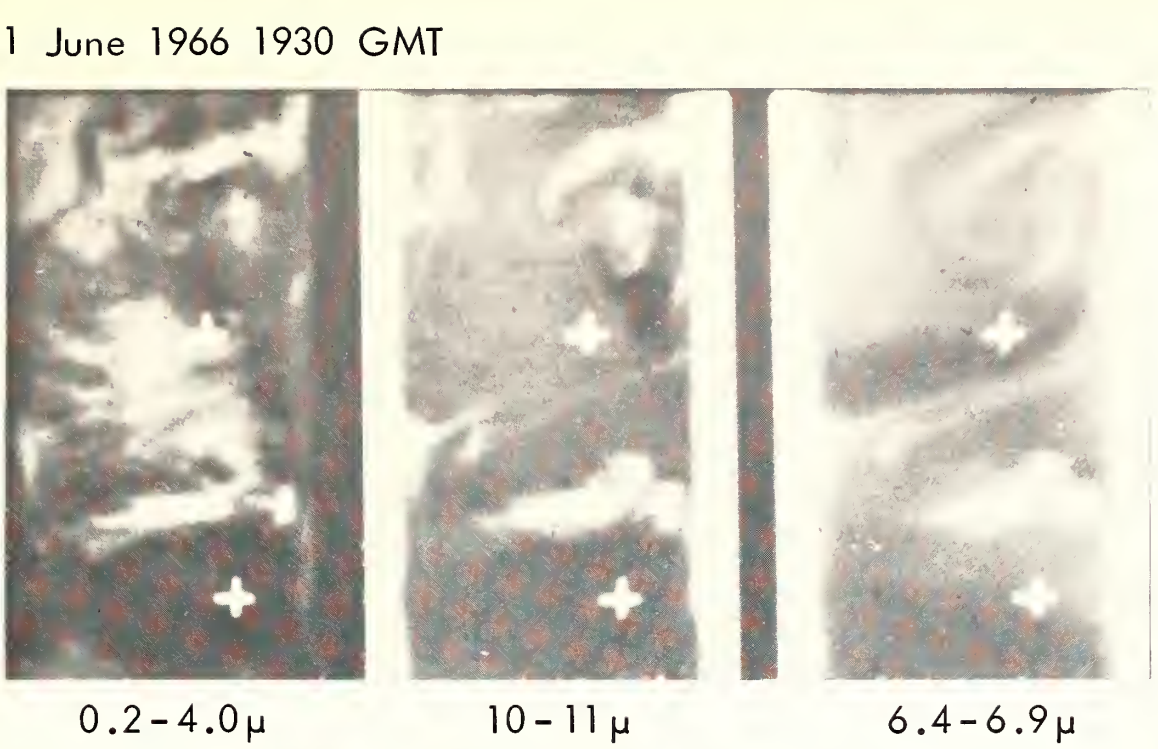


Figure 3.6-2. Multi-band imagery. This Medium Resolution Infrared (MRIR) example from Nimbus 2 (1 and 2 June 1966, 1900Z) illustrates how existence of a jet stream can be deduced from multi-spectral data. Dark streak in water vapor absorption band (6.4 to 6.9μ) and white streak in infrared "window" (10 to 11μ) are almost absent in the solar radiation spectrum (0.2 to 4.0μ). This indicates characteristic band of dry, descending air in upper troposphere bounded on the southern side by cirrus bands typical of jet streams. California coast is visible on center pictures.

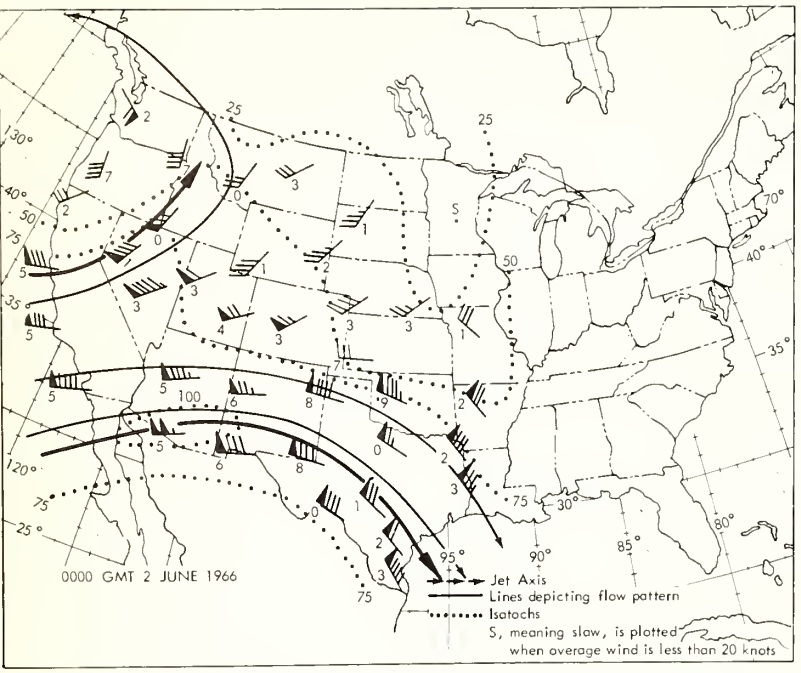

0000 GMT 2 JUNE 1966
Jet Axis
Lines depicting flow pattern
Isotachs
S, meaning slow, is plotted when overage wind is less than 20 knots

Figure 3.6-3. Map of maximum upper winds on 2 June 1966 0000Z confirms jet stream location indicated in satellite images of Fig. 3.6-2.

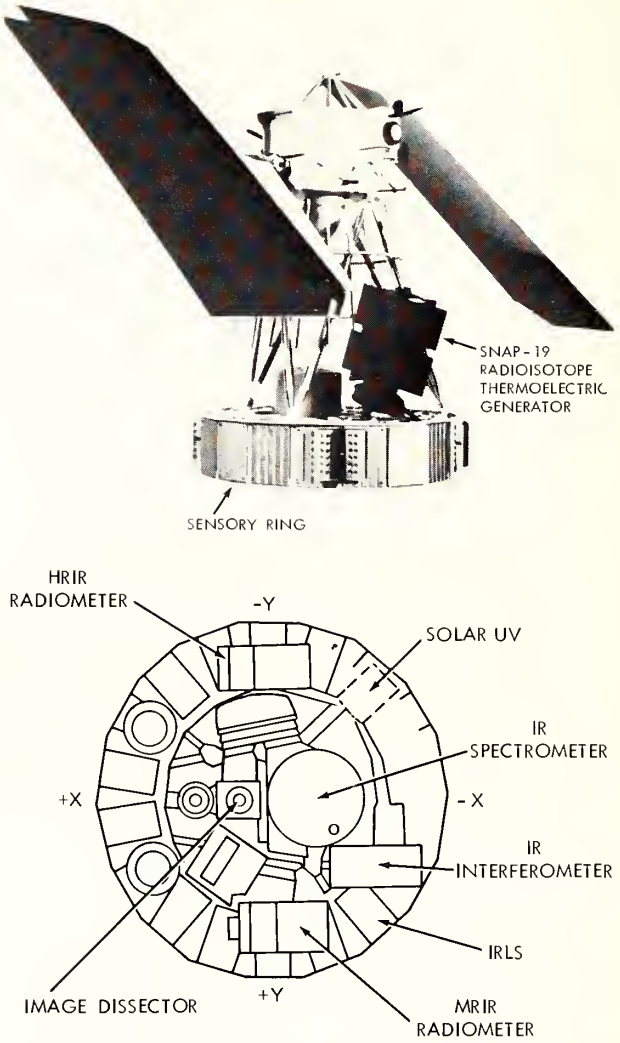


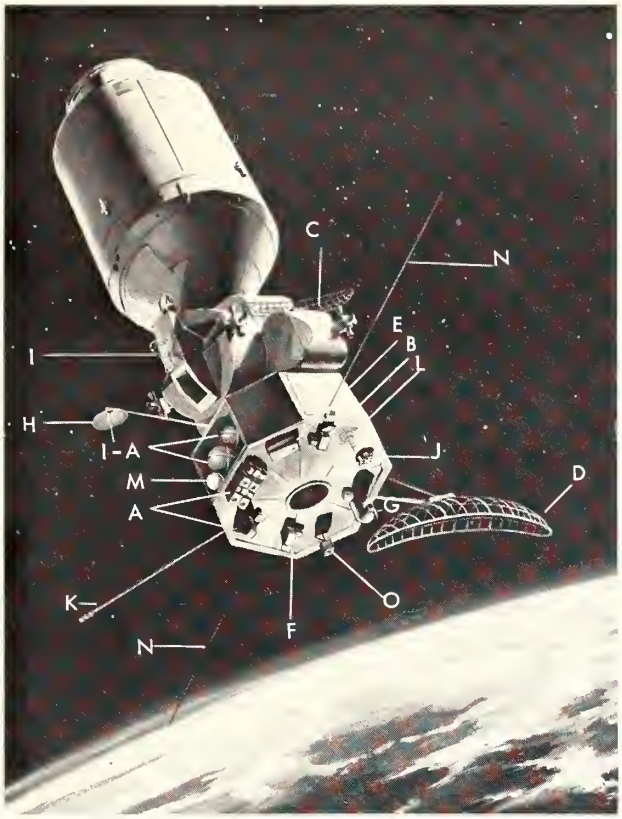
Figure 3.6-4. Advanced version of the Nimbus satellite, a large observatory spacecraft for research and development with interrelated meteorological experiment. (Photo courtesy NASA).

An interesting example of such multi-purpose satellites, the OGO (Orbiting Geophysical Observatory) is shown in Figure 3.6-1. A spacecraft in excess of 1,000 lbs., it carries up to 20 experiments in standard modules and permits a very flexible exposure of different sensors which can be independently oriented. As a research tool it is a very economical experiment carrier and, except for their common orbit, the geophysical experiments may be independent of each other.

Another type of observatory satellite carries a set of interrelated experiments which are carefully selected so that they systematically complement each other. The advantage of multiple remote sensing of the same target is such that this type of "observatory" spacecraft is most desirable for monitoring complex phenomena.

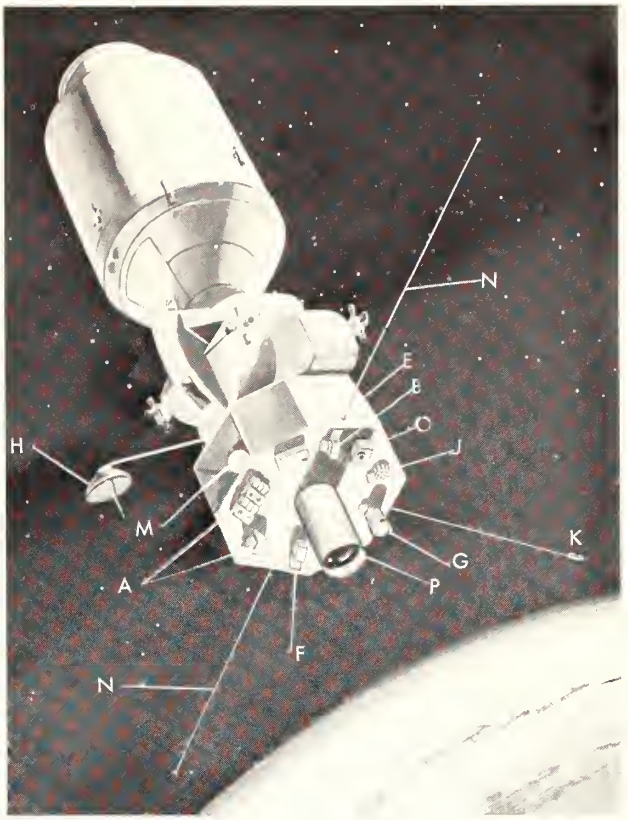
The Nimbus satellite, also in the 1,000 lb. class, has shown that multi-spectral imaging of the atmosphere reveals features which can be detected only by comparing results in different spectral bands. Figures 3.6-2 and 3.6-3 show an example where the position of the jet stream can be deduced from comparing multi spectral images (Whitney, 1966).

The energy for the images in the different columns of Figure 3.6-2 is emitted by a different source. In the left column it is essentially reflected sunlight (0.2 to 4.0μ wavelength); in the center, infrared radiation emitted by cloud tops or by the ground (10-11μ); and in the right column infrared radiation emitted by atmospheric water vapor (6.4 to 6.9μ). Thus, the left column resembles a visible image, while the middle and right columns depict warm (dark) and cold (bright) areas. In the troposphere this is equivalent to the emitting radiation sources being at low elevations in the dark areas and at high elevations in the bright areas. Therefore, the dark band from SW to NE near 30° latitude in the pictures to the right must be interpreted as being caused by a low level water vapor atmosphere, that is by descending (dry) air, while the white streak just south of it in the lower center picture, must be interpreted as a band of high level water vapor or clouds. The fact that both features are barely



A. FRAME & PANORAMIC CAMERA
B. LINE SCAN CAMERA
C. RADAR SCATTEROMETER
D. RADAR
E. MICROWAVE RADIOMETER
F. INFRARED RADIOMETER
G. SPECTROMETER (INFRARED)
H. SPECTROMETER (MICROWAVE)
I. REFRACTOMETER
I.-A. SATELLITES
J. PHOTOMETER
K. MAGNETOMETER
L. SPHERICS MONITOR
M. GRAVITY GRADIOMETER
N. IONOSPHERIC MAPPING EQUIPMENT
O. TV CAMERA

Figure 3.6-5. Artist's concept of an Apollo type manned space observatory carrying multiple equipment for earth-oriented observations of the geophysical environment. It would be necessary for such a vehicle to be in low earth orbit at high orbital inclination. (Photo courtesy NASA).



A. FRAME & PANORAMIC CAMERA
B. LINE SCAN CAMERA
E. MICROWAVE RADIOMETER
F. INFRARED RADIOMETER
G. SPECTROMETER (INFRARED)
H. SPECTROMETER (MICROWAVE)
J. PHOTOMETER
K. MAGNETOMETER
M. GRAVITY GRADIOMETER
N. IONOSPHERIC MAPPING EQUIPMENT
O. TV CAMERA
P. TELESCOPE

Figure 3.6-6. Artist's concept of an Apollo type manned space observatory similar to Figure 3.6-5 but with instrumentation modified for synchronous orbit.

distinguishable in the visible range (left column) indicates that the cloudband is cirrus (which is nearly transparent in the visible spectrum) and that this long cirrus band parallels the clear area of dry descending air to the north. This situation is typical for jetstreams; Figure 3.6-3, a maximum wind map, confirms this conclusion. The position of the jet-stream across Baja California, which is visible in the center pictures of Figure 3.6-2 as a dark (warm) peninsula, is marked by the bright cirrus band.

Similar techniques permit the scientist to detect ocean currents and vertical motions of the atmosphere. An advanced version of Nimbus is shown in Figure 3.6-4. This is a good example of a design for a research and development spacecraft for closely interrelated experiments.

While observatory satellites carrying unrelated or interrelated experiments are useful for research, a service oriented agency whose operations depend on

continuous data flow has to take additional considerations into account.

If one out of 20 vital experiments is lost the user agency will not be willing to pay for the launch of another entire observatory. A large service and research agency may, however, be interested in satisfying a maximum of its requirements with a minimum of space vehicles and data processing problems. The simultaneously existing requirements for high reliability and long life time then point to a special type of observatory spacecraft in which reliability is not sacrificed to the number of experiments, and in which sufficient redundancy and possibly a predesigned maintenance and repair capability are provided (see 3.4). This type of orbiting observatory does not exist yet.

The observatory concept, if applied to interrelated multiple experiments, is also attractive from the standpoint of operational data handling. Corrections for altitude, orbital parameters, computerized "gridding," "rectifying," "mosaicing," etc. can be done in one process. Multiple data over the same area of the earth's surface will be available simultaneously. For a user agency such as ESSA, with multi-disciplinary data requirements and a large operational data handling capability, this becomes a primary consideration.

Figures 3.6-5 and 3.6-6 are concepts of manned space platforms for the environmental sciences. They are essentially Apollo spacecraft converted to carry complete arrays of environmental sensors on a modified Lunar Module (LM). Here the lunar descent stage of the LM and the Apollo Command Module are pressurized for the crew.

Figure 3.6-5 depicts a low flying "LM LAB," preferrably in a high inclination orbit, with elaborate high resolution instrumentation; Figure 3.6-6 illustrates a similar spacecraft modified for synchronous orbit, carrying a telescope and a reduced set of instruments.

These manned laboratories may be considered early forerunners of a full sized manned space station. With their power supplies and weight capacities they are able to carry the full load of instrumentation discussed in Section 3.1, but their lifetime is short. A one year (polar or earth synchronous orbit) capability is desirable and is considered more important than continuous by the crew. As follows from our discussion in Section 3.4, the equipment oriented crew functions (checkout, deployment, maintenance, repair, R&D testing) require only temporary occupation of the spacecraft. The same is true for research oriented observer functions. Therefore, a time restriction life support system for the crew does not necessarily limit the overall life time of a spacecraft; between crew visits, it may be put into an automatic mode. This combination of manned and unmanned operation of a complex observatory type space platform appears particularly attractive for the environmental sciences. The optimum combination of manned and unmanned observatory or special purpose satellites will depend on careful cost and benefit studies by the user agencies. There is little doubt that a national system will incorporate both observatory and special purpose satellites.

3.7 THE NEED FOR A NATIONAL PROGRAM

In a report to the Administrator of ESSA, the members of the task force had, naturally, to focus their attention on the environmental sciences and the specific requirements of this agency. During the course of the study, however, the group became increasingly aware of the multidisciplinary nature of the systems under consideration and the need for cooperative and coordinated efforts where space systems are used. Certainly, ESSA is not the only agency which has studied new avenues for research and services opened up by the remote sensing possibilities from space. In conjunction with NASA, the U. S. Navy, the Department of Interior, the Department of Agriculture and other agencies have, during the past two years, applied their professional competence to extensive studies of the application of this relatively new technology to their special needs. While there are differences in emphasis and in requirements, such as time and resolution, the commonality of sensors, space vehicles and data handling is striking.

Looking at the *sensors* summarized in Table 3.1-A we find, for example, the following: A high resolution multi-band camera system in the visible and near visible spectral range fulfills requirements in agriculture for determinating snow, grass and timber lines, in geology for locating minerals, in oceanography for charting shoals and sea ice, in meteorology for observing cloud developments. A high resolution infrared imaging system in turn is useful in agriculture for surveys of crop types and crop damage, in geology for the detection of thermal anomalies, in oceanography for the study of sea surface temperature and currents, in meteorology for the measurement of surface and cloud top temperatures. Similar multidisciplinary applications exist for radar and other remote sensing systems.

With respect to *space vehicles* the cost and complexity of satellites, launch vehicles and supporting ground equipment make it important that the government make the most efficient use of existing and future systems. Surely, it would be wasteful for each agency to demand its own separate spacecraft and ground system, unless it is needed from a standpoint of technical incompatibility.

Also the *data handling* problem is common to many disciplines and government agencies. As pointed out in Section 3.3 the expected data volume is unprecedented. It will require early development decisions on software and data handling equipment. Without such decisions the user agencies will either drown in a flood of raw data or they will have to ignore the potential benefits of the available space capability. Although meteorological data needs are perhaps more severe than others – in view of the "real-time" requirements of the meteorological forecaster – ESSA's data handling experience with the first operational satellite imaging system clearly indicates a formidable data problem for the coming global, high resolution multisensor systems. Duplication of ground data hardware and software will be prohibitively expensive; early, joint planning and information exchange by the user agencies with respect to the data problem will be of essence.

It therefore seems to us that the related needs of the users with respect to instrumentation, space vehicles and data handling systems make it imperative for the interested parties to take joint steps, at an early time, toward full coordination of and collaboration in national activities involving earth-oriented utilization of space technology. It then is conceivable that the vast facilities available at these agencies (including aircraft, ships, computers, etc.) can be used systematically and in a well planned cooperative effort to fully exploit the information available from spacecraft.

chapter 4

CONCLUSIONS AND RECOMMENDATIONS

A number of specific conclusions and recommendations are contained in the body of the report. Others, of a broader nature, evolve from an overall view of the results of this study. In this chapter the major conclusions and recommendations of the task force are summarized as follows:

The study indicates that future space platforms will be capable of acquiring global geophysical data on an unprecedented scale for a wide range of environmental disciplines, in support of both research and services. This is reflected in the large number of experiment proposals (nearly 150) considered by the task force. Approximately 25 of these are discussed in more detail in the report (Chapter 2). The different disciplines show impressive commonality in data requirements.

Convinced that manned and unmanned spacecraft supplement but do not exclude each other, the task force feels that an optimum combination of manned and unmanned space vehicles should be applied to future environmental science and service systems.

An analysis of the data handling problem shows that an orbiting environmental observatory may provide data at such a rate that bottlenecks will develop on the ground unless efforts for improvement in software, data handling equipment and display devices are started in the immediate future. Early establishment of a program for ground system development is urged; a program which would assure the required operational improvements with respect to computers and associated peripheral equipment (increased storage capacity and speed), bandwidth for ground communication links, display devices and especially the necessary software. (See 2.3).

Many of the remote sensors required for the environmental sciences are either available now or under development. Others which hold great promise for the environmental sciences need to be developed and tested. This is particularly true for radio occultation systems, remote wind sensing systems, radar scatterometer techniques and special spectral radiometers for the measurement of absolute surface temperatures. (See Table 3.1-A).

Total weight, power and volume of a meaningful instrument package for the environmental sciences, if placed on the same spacecraft, are estimated to be of the order of several thousand pounds, several kilowatts and several hundred cubic feet, respectively. (See 3.1).

Saturn-Apollo class vehicles offer impressive capabilities for using complex, multiple in-

strumentation systems and for crew participation. These vehicles are attractive for both manned and unmanned observatory type spacecraft in spite of certain limitations in lifetime and orbital parameters imposed on early manned flights. (See 1.3 and 3.6).

The task force rates highly (see 3.4) a space vehicle capability:

- to service and repair, in orbit, vital components of unmanned spacecraft,
- to provide a semi-automatic mode for manned spacecraft such that on board systems continue to operate after the flight crew leaves,
- to launch from orbit after proper checkout, subsatellites, special probes and recovery capsules.

A careful analysis of man's usefulness in space, from a research and operational standpoint yields the following functions:

- Operator function (equipment oriented)
- Service function (equipment oriented)
- Observers function (phenomena oriented)
- Pilot function (flight oriented)

The significance of the scientific observer function will become clear once a primary scientific mission has been flown with a highly qualified scientist onboard. The majority of the proposed measurements can be performed on either manned or unmanned spacecraft. In most cases, man is considered useful, but not essential. A smaller number of proposals lists man as either essential or undesirable. (See 3.4).

Large unmanned observatory type spacecraft should be considered if:

- reliability is not sacrificed to the number of experiments, but sufficient redundancy is provided for all vital onboard systems;
- lifetime in excess of one year is assured by a built-in maintenance and repair capability;
- optimum orbital height for complete global coverage is selected.

Special purpose satellites should be considered if unusual orbits are required or if experiments are incompatible with other onboard systems. (See 3.6).

Most environmental science experiments require polar or earth synchronous orbits. For complete daily global coverage, circular polar orbits in excess of 1,000 km height are desirable. To observe features which change slowly with time, lower orbital heights are acceptable. For rapidly changing features, overlapping patterns of consecutive orbits show that the possibilities for a second look at the same phenomenon within a reasonably short period of time are restricted to a narrow zone near the latitude of orbital inclination. Earth synchronous satellites properly spaced around the globe deserve the highest degree of priority (see 3.2).

Multiple, simultaneous sensing of closely related parameters is considered highly desirable over the same geographic area because it yields corroborative data otherwise not obtainable. Many of the sensors listed in this study fulfill multidisciplinary requirements. (See 3.1 and 3.6).

Selection of astronaut-scientists with excellent background in the geophysical or environmental sciences is recommended; ESSA would offer special training in its varied disciplines, programs and facilities. (See 3.4).

Based on the commonality of sensors, spacecraft and data handling requirements the task force recommends that the interested user agencies take joint steps, at an early time, toward full coordination of and collaboration in national activities involving earth-oriented utilization of space technology.

APPENDIX A – REFERENCES

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